NOVEMBER, 1947
VOLUME 3
NUMBER 11

☆

STAFF

Editorial

IVY M. PARKER
Editor

W. M. WERNETT
Managing Editor

Correspondents

ARBA H. THOMAS
Metallurgy

BRUCE L. COREY
Oil Pipe Lines

WM. A. CUNNINGHAM
Education

HENRY W. FOELSCH
Coatings for Metals

A. J. GATES
Water Works

L. J. GORMAN
Electric Power Generation, Transmission, Distribution

FRANK W. JESSEN
Petroleum Production

B. B. MORTON
Metallurgy, Non-Ferrous

V. L. NEALY
Petroleum Refining

WALTER J. PRICE
Dock Facilities

RALPH A. TROUPE
Chemical Manufacturing

Advertising

A. B. CAMPBELL
(Executive Secretary of NACE)
Advertising Manager

☆

GENERAL OFFICES

Southern Standard Building
711 Main Street
Houston 2, Texas

Subscription: (See note on Page 4, News Section). $5.00 per year to non-members; Member's dues $7.50, of which $3.00 are applied as subscription to CORROSION. Additional copies to members 50 cents, to non-members 75 cents. Foreign remittances should be by international postal or express money order or bank draft negotiable in the U. S. and for an equivalent amount in U. S. funds.

Entered as second class matter October 31, 1946 at the Post Office at Houston, Texas, under the act of March 3, 1879.

Copyright 1947 by the National Association of Corrosion Engineers.

Reproduction of the contents, either as a whole or in part, is forbidden unless specific permission has been obtained from the Editor of CORROSION. Articles printed represent the opinions of their authors, and not necessarily those of the Editors of CORROSION, or the Officers or Members of the National Association of Corrosion Engineers. Manuscripts to be considered for publication should be forwarded, together with illustrations, to the Editor of CORROSION, 815 Southern Standard Building, Houston 2, Texas.

Corrosion

devoted entirely to

CORROSION

Research and Control

PUBLISHED MONTHLY AS ITS OFFICIAL JOURNAL, BY THE NATIONAL ASSOCIATION OF CORROSION ENGINEERS, INC., AT HOUSTON, TEXAS, U. S. A., TO PROVIDE A PERMANENT RECORD OF PROGRESS IN THE CONTROL OF CORROSION AS DESCRIBED IN PAPERS PREPARED FOR THE ASSOCIATION AND FROM OTHER SOURCES.

CONTENTS

Location and Selection of Anode Systems For Cathodic Protection
By D. B. Good 539

Electrical Instruments and Measurements in Cathodic Protection
By J. M. Pearson 549

Surface Studies of Metals from the Corrosion Standpoint
By M. G. Fontana 567

Regalvanizing of Welded Joints
By George H. Ohmer 580

Cathodic Protection of Hot Water Tanks
By J. M. Bialosky 585

A Message from Your Officers 1

NACE News 2

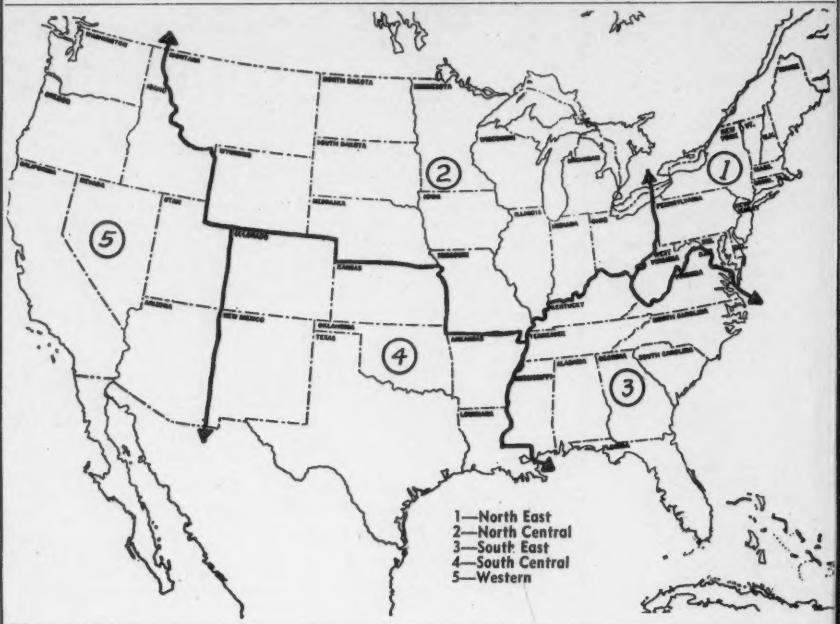
Corrosion Abstracts 9

Index to Advertisers 30

THIS MONTH'S COVER

• *Reconditioning a pipeline. One of several operations in the process, this machine gives the pipe a stiff brushing with revolving wire brushes after it has been inspected for weak spots, and spot welding and patching completed. In addition, the machine applies a coat of dilute coal-tar primer. Later, another machine will apply a coat of heavy protective coal-tar enamel and a wrapping of impregnated felt. This is but one means the gas and oil industries use to combat corrosion on the estimated 600,000 miles of transportation lines in this country. Cathodic protection, another means, is used either alone or in conjunction with various coatings and pipe wrapping materials. Photograph courtesy Gulf Pipe Line Corp., Houston, Texas.*

REGIONAL DIRECTORY OF NACE



Regional Officers . . . .

North East Region

R. Pope, Bell Telephone Laboratories, Inc., New York, N. Y. ..... Director
J. M. Pearson, Sun Oil Company, Chester, Pa. ..... Chairman
A. S. Brookes, Public Service Electric & Gas Co., Newark, N. J. ..... Vice Chairman
F. R. Arnoldy, American Telephone & Telegraph Co., New York, N. Y. ..... Secretary-Treasurer

North Central Region

H. J. McDonald, Illinois Institute of Technology, Chicago, Ill. ..... Director
L. F. Greve, Commonwealth Edison Co., Chicago, Ill. ..... Chairman
H. A. Robinson, Dow Chemical Co., Midland, Mich. ..... Vice Chairman
H. A. Ronningen, Ronningen Engineering Sales, Vicksburg, Mich. ..... Secretary-Treasurer

South East Region

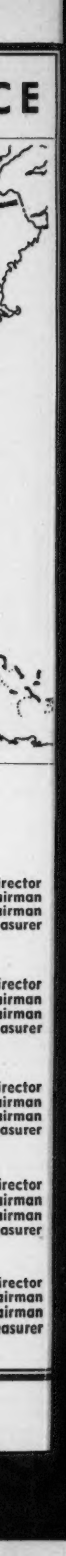
E. B. Ayers, Plantation Pipe Line Co., Atlanta, Ga. ..... Director
E. B. Ayers, Plantation Pipe Line Co., Atlanta, Ga. ..... Chairman
J. T. MacKenzie, American Cast Iron Pipe Co., Birmingham, Ala. ..... Vice Chairman
A. C. Nelson, Plantation Pipe Line Co., Atlanta, Ga. ..... Secretary-Treasurer

South Central Region

L. F. Scherer, Texas Pipe Line Co., Houston, Texas ..... Director
A. N. Horne, Texas Empire Pipe Line Co., Tulsa, Okla. ..... Chairman
Derk Holsteyn, Shell Oil Co., Inc., Deer Park, Texas ..... Vice Chairman
T. F. P. Kelley, James E. Mavor Co., Houston, Texas ..... Secretary-Treasurer

Western Region

F. A. Hough, Southern Counties Gas Co., Los Angeles, Calif. ..... Director
V. N. Jenkins, Union Oil Co., Wilmington, Calif. ..... Chairman
D. Blackburn, Pasadena Water Department, Pasadena, Calif. ..... Vice Chairman
Guy Corfield, Southern California Gas Co., Los Angeles, Calif. ..... Secretary-Treasurer


CE
rector
irman
irman
asurer
rector
irman
irman
asurer
rector
irman
irman
asurer
rector
irman
irman
asurer
rector
irman
irman
asurer

Location and Selection of Anode Systems for Cathodic Protection Units*

By D. B. Good*

IT IS WELL to emphasize the importance of the proper location and selection of anode systems for use in providing cathodic protection for the mitigation of corrosion on sub-surface structures. The anode is one of the major factors that may be varied or controlled in such a system. This article deals only with anodes placed in the earth's surface.

The location of an anode oftentimes influences the required size of the anode, the rectifier rating, the power costs, and consequently the cost per mile per year of cathodic protection for an underground structure.

The total circuit resistance of a cathodic unit herein discussed consists of the following:

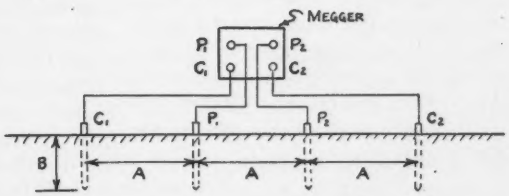
1) Pipeline resistance to earth (^{R}PL).
2) Resistance of the wire and pipe in the d-c circuit (^{R}W).
3) Resistance of the anode to earth (^{R}G).

The resistance of the soil between the points 100 diameters or so from the pipeline and anode is usually considered equal to zero.

1) The pipeline resistance to earth may be small or large, depending upon soil conditions and the status of the pipe coating. The pipe coating constitutes the major part of the pipeline resistance to earth, as the ^{R}PL of a long bare pipe is very small.

In the areas of low soil resistivity and for a condition of only fair to poor coatings, the pipeline resistance to earth may be in the order of a few hundredths of an ohm. In medium to high resist-

DETERMINING RESISTIVITY OF SOIL BY MEGGER AND FOUR BAR METHOD



In U. S. Bureau of Standards Bulletin No. 258, Dr. F. Wenner describes this method. If B is small compared to A, as is the case when the electrodes are at the surface of the earth, then $\rho = 2\pi AR$. The resistivity ρ, is in ohms per centimeter cube, where A is in centimeters and R is the reading of the instrument in ohms. By this method the average value of ρ is determined to a depth equal to A.

FIGURE 1

★A paper presented at the Annual Meeting of NACE in Chicago, Ill., April 7-10, 1947.

* Corrosion Engineer, The Texas Pipe Line Company, Tulsa, Okla.

ance soils and fair to good coatings, ^{R}PL has been generally found to fall in the limits between 0.05 and 0.60 ohm, and may be higher in some cases.

In Oklahoma, Kansas, Missouri and Illinois, a ^{R}PL of 0.1 to 0.3 ohm is not uncommon for fair coatings and the soil resistivities encountered. This is an important factor in the design of a ground bed as will be shown.

Pipeline resistance to earth is a partially controllable factor in the designing of a new line. For a coating with high resistance, ^{R}PL will be high, compared to the ^{R}PL for a poor coating. For a line in place, it is, for this discussion, considered an uncontrollable item.

2) The second item, "Resistance of wire and pipe in the d-c circuit," is controllable to the extent that a choice may be made of the resistance of the wire used in the negative and positive feeders.

3) The third part of the total circuit resistance, the "Anode resistance to ground," is partly controllable. The amount and distribution of anode that is used is flexible, except in restricted ground areas and where anode material is limited. The soil in which the anode is placed may be determined by selection. Sometimes this area of selection is limited by right-of-way restrictions, easement difficulties, etc.

Locations of Anode Systems

The locations of cathodic units on a pipeline system are usually determined by the amount of pipe that can be protected and by the availability of power. Where power is being supplied or generated at the cathodic unit, the locations can be determined by test generators, and the availability of outside power is not a factor.

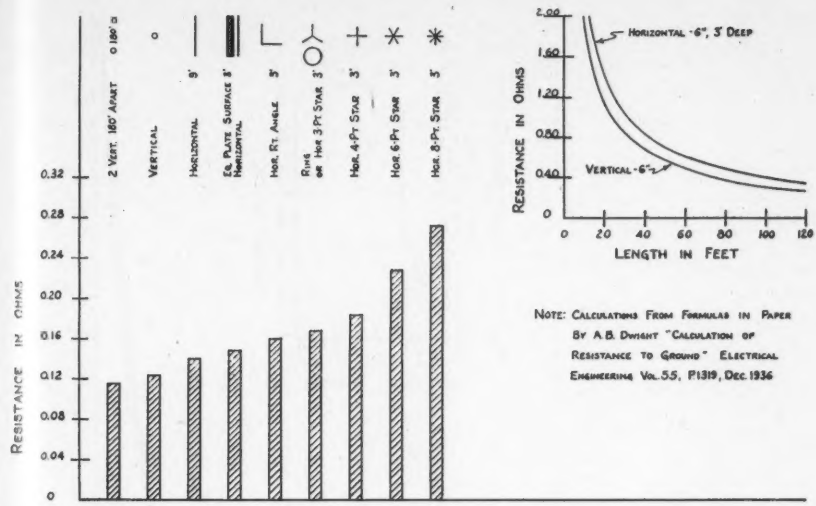
Assume then, that power is available at a point acceptable for the location of a cathodic unit. This point may be determined by soil resistivity comparisons and by the use of test generators.

Acceptance of surface indications of soil resistivity may sometimes be necessary. However, it is not the preferred approach and cannot be depended upon in the selection of low resistance soils.

Soil resistance, actual or relative, may be determined by several methods, of which a few are: By Shepard canes; radio balance; laboratory test of soils; megger and four bar method.

Visual Selection of Anode Site

Without the measurement of soil resistivity, the location of the anode may be made by surface indications. This visual selection often may be misleading. Frequently the low wet area may have a higher soil resistivity than an adjoining area not so low or wet. This is particularly true where the terrain varies from lowlands to hilly land in short distances, because the low areas may be fills of higher resistance top soils. However, other things being equal, moist or wet locations should be selected for ground beds. Where this is impossible, excellent results have been obtained by placing farm tile over the anode. Current densities should be kept low to prevent undue drying out of the soil around the anode.



COMPARATIVE EFFICIENCIES OF VARIOUS GROUND DESIGNS
SOIL IS OF 1000 OHMS/CC RESISTIVITY. IN EACH CASE 360' OF 6" PIPE IS USED, OR THE EQUIVALENT THEREOF. 3', ETC. MEANS GROUND IS BURIED AT 3 FOOT DEPTH.

FIGURE 2

Average Soil Resistivity by Megger and Four Bar Method

We will concern ourselves with the megger and four bar method of determining average soil resistivities. (See Figure 1.) By the use of the megger, the average soil resistivity is determined to a depth which corresponds to the distance A between the electrodes, equally spaced in a straight line. In practice, the spacing may be varied between four and fifty feet. Usually the soil resistivity reading obtained by 10 or 25-foot spacings will show good correlation with the actual circuit resistance obtained on final installation. Best results are obtained in fairly uniform soil, of course, and some erratic results may be expected in rocky terrain.

Anode Configuration

Having determined the area of lowest soil resistivity, a selection of the anode configuration can now be accomplished. Figure 2 shows the relative efficiency of some various configurations. It is to be seen that a vertical anode 360 feet deep is more efficient than a 360-foot length of horizontal anode, and in turn, the 360 feet of horizontal anode is more efficient than any of the other configurations shown, all containing 360 feet of anode material.

From practical standpoints, the horizontal type of anode system is generally to be preferred in regions where soil resistance changes quite decidedly with depth. The choice of anode configuration will depend upon specific conditions, such as soil

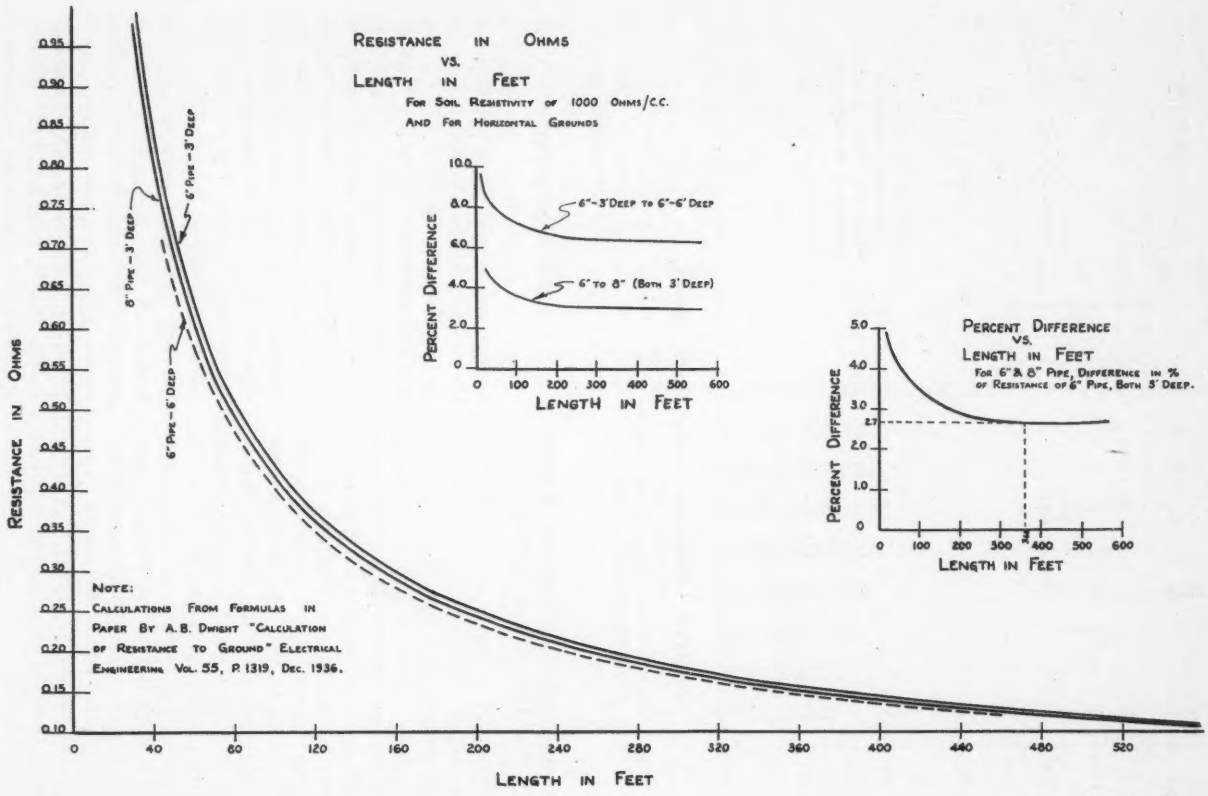

RESISTANCE IN OHMS
VS.
LENGTH IN FEET
FOR SOIL RESISTIVITY OF 1000 OHMS/C.C.
AND FOR HORIZONTAL GROUNDS
RESISTANCE IN OHMS
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
6" PIPE - 3' DEEP
6" PIPE - 3' DEEP
6" PIPE - 6' DEEP
0
40
80
120
160
200
240
280
320
360
400
440
480
520
LENGTH IN FEET
NOTE:
CALCULATIONS FROM FORMULAS IN PAPER BY A.B. DWIGHT "CALCULATION OF RESISTANCE TO GROUND" ELECTRICAL ENGINEERING VOL. 55, P. 1319, DEC. 1936.
PERCENT DIFFERENCE
10.0
8.0
6.0
4.0
2.0
0
6"-3' DEEP TO 6"-6' DEEP
6" TO 8" (BOTH 3' DEEP)
0
100
200
300
400
500
600
LENGTH IN FEET
PERCENT DIFFERENCE
VS.
LENGTH IN FEET
FOR 6" & 8" PIPE, DIFFERENCE IN % OF RESISTANCE OF 6" PIPE, BOTH 3' DEEP.
PERCENT DIFFERENCE
5.0
4.0
3.0
2.7
2.0
1.0
0
0
100
200
300
400
500
600
LENGTH IN FEET

FIGURE 3

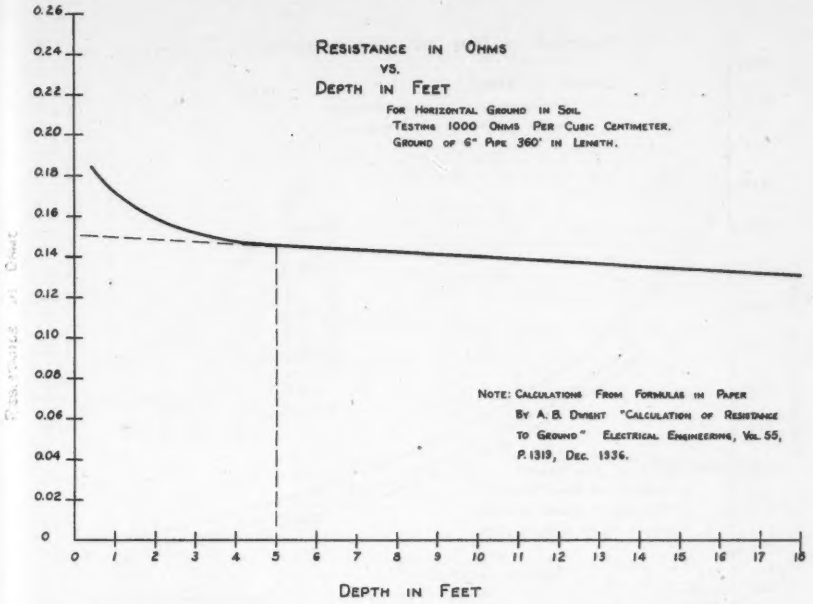


FIGURE 4

resistivity, soil substructure, amount of current to be discharged, space limitations, and individual preferences.

Figure 3 shows curves of "Resistance in Ohms versus Length in Feet" for a horizontal anode in a soil of 1000 ohms per cubic centimeter resistivity. Also shown are curves indicating the percent difference between 6-inch pipe 3 feet deep, and 6 feet deep and difference in percent between 6-inch and 8-inch pipe both 3 feet deep. It is seen that there is only 2.7 percent difference beteween 6-inch and 8-inch pipe both 3 feet deep for lengths over 300 feet.

Figure 4 shows the curve of "Resistance in Ohms versus Depth in Feet" for horizontal grounds. It is seen that at a 5-foot depth a 360-foot ground in 1000 ohms per cubic centimeter has a value of approximately 0.145 ohm, while a similar ground 9 feet deep has a resistance of approximately 0.140 ohm. Other things being equal, a ground should be placed at least from 3 to 5 feet deep, on the basis of the above information. Also, permanent moisture is likely to be encountered at appreciable depths.

Figure 5 shows curves of "Resistance in Ohms versus Length in Feet" for 3-, 6- and 9-foot depths of a 6-inch pipe in soil of 1000 ohms per cubic centimeter resistivity. For a 550-foot length of anode there is about 10 percent difference in resistance to ground between the 3-foot and 9-foot depth.

Figure 6 shows curves for "Resistance in Percent versus Spacing Between Rods in Rod Diameters." This

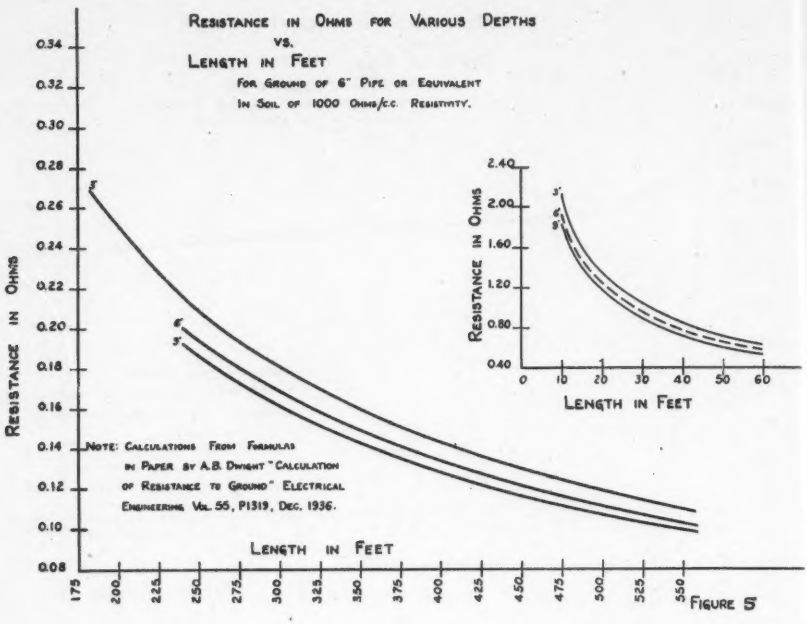


FIGURE 5

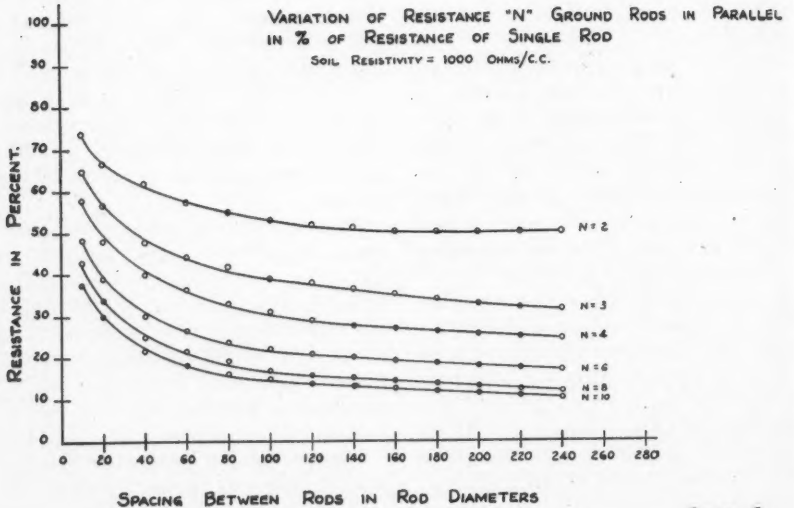


FIGURE 6

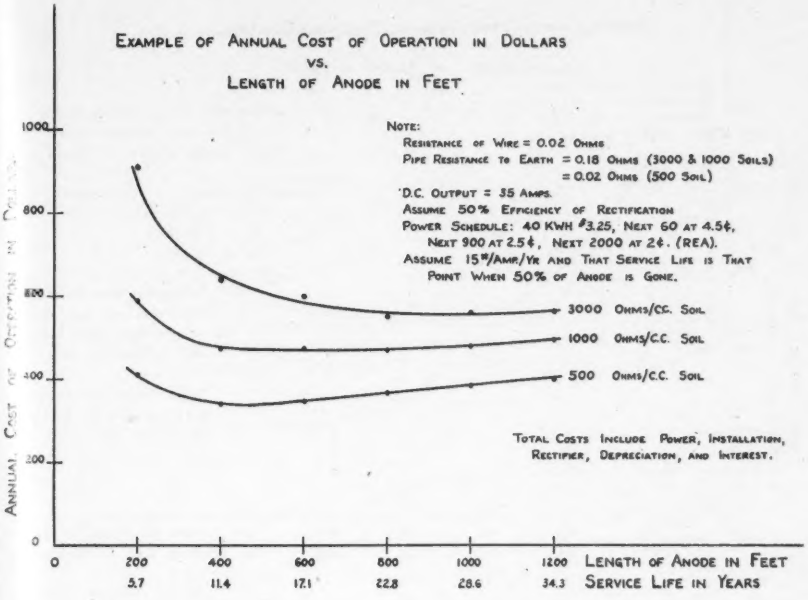


FIGURE 7

is useful in laying out multiple or distributed grounds as one can predetermine the efficiency of the spacing of the grounds. It is seen that 160 to 240 diameters spacing is required for from 2 to 10 rods to get the effect of parallel resistances.

Before the actual installation of a cathodic unit, it is important to determine the soil resistivity and ^{R}PL; for, from calculated curves, one may determine with reasonable accuracy the economical design of a cathodic unit.

Economical Anode Length

Figure 7, as an example, shows the economical length of anode that may be selected by knowing the average resistivity of the soil, the power rate, the current that is to be discharged from the anode, the resistance of the pipeline to ground, and the number of years that the unit is expected to operate.

The service life is shown on the basis of an assumed loss of metal of 15 pounds per ampere per year and being at a point of time when 50 percent of the metal remains. This gives a conservative life expectancy. The rate loss can be varied to suit any other basis desired, as individual experience may dictate. If one uses 10 pounds per ampere per year, multiply the service life shown by 1.5. By connecting the positive cable to the anode at numerous points and by doping a small strip down the top of the rail or junk pipe, a more equal distribution of current to ground may be obtained, and the service life extended.

It is interesting to note that for the conditions set up, the economical

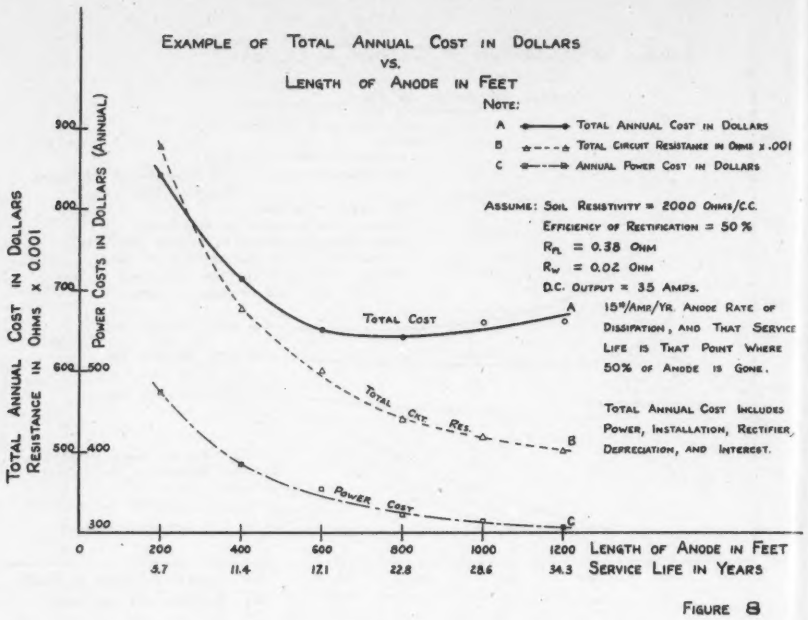


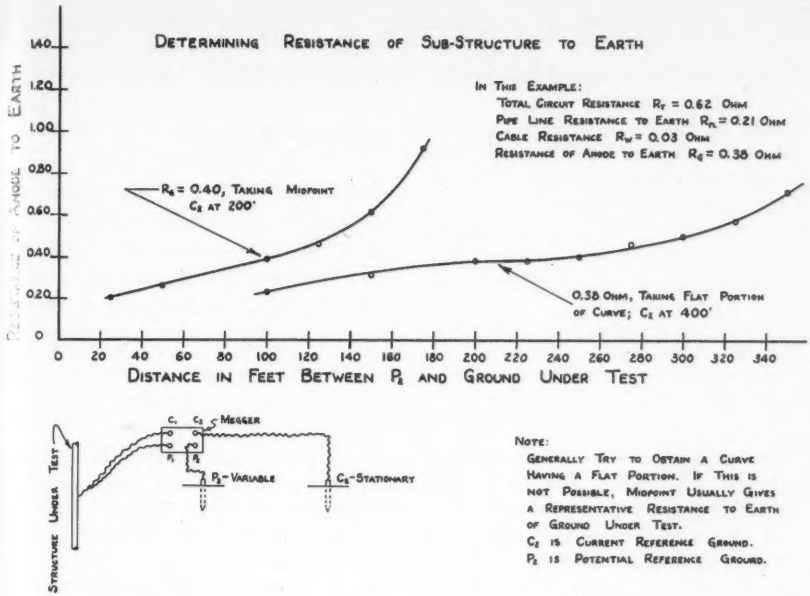
FIGURE 8

lengths of anode for the 3000, 1000 and 500 ohms per cubic centimeter soils are about 800 feet, 600 feet, and 400 feet, respectively. These curves are intended to show a trend only. Each case must of course be figured on its own merits, evaluating the various factors involved. In each case an inspection and maintenance cost has been added in, along with cost of anode, cable, rectifier, depreciation and interest on each item, and power costs.

These curves emphasize the fact that with higher resistance soils, economies point toward larger anode systems than for lower resistance soils, with extensive service life being desired in both cases. Also for the lower resistance soils, the curve showing the total cost of operation is seen to be flatter, which means that the length of anode used in a ground bed is not so critical from the point of economy but is determined mainly by the service life required.

Figure 8 is an example where different factors are assumed than for Figure 7. Here a soil of 2000 ohms per cubic centimeter is used and a pipeline resistance to ground of 0.38 ohm is assumed as against 0.18 ohm for Figure 7. It is seen that the curve of total annual cost is steeper than the previous ones, and that from 600 to 800 feet of anode is an indicated economical length for extended service life and that for longer than an 800-foot length, the cost begins to rise.

In all cases, of course, the power cost continues to decline with increase of anode length, as well as


DETERMINING RESISTANCE OF SUB-STRUCTURE TO EARTH
RESISTANCE OF ANODE TO EARTH
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0
IN THIS EXAMPLE:
TOTAL CIRCUIT RESISTANCE R_T = 0.62 OHM
PIPE LINE RESISTANCE TO EARTH R_{PL} = 0.21 OHM
CABLE RESISTANCE R_W = 0.03 OHM
RESISTANCE OF ANODE TO EARTH R_E = 0.38 OHM
R_E = 0.40, TAKING MIDPOINT C_2 AT 200'
0.38 OHM, TAKING FLAT PORTION OF CURVE; C_2 AT 400'
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340
DISTANCE IN FEET BETWEEN P_2 AND GROUND UNDER TEST
C_1 C_2 P_1 P_2 MEGGER
P_2 - VARIABLE
C_2 - STATIONARY
STRUCTURE UNDER TEST
NOTE:
GENERALLY TRY TO OBTAIN A CURVE HAVING A FLAT PORTION. IF THIS IS NOT POSSIBLE, MIDPOINT USUALLY GIVES A REPRESENTATIVE RESISTANCE TO EARTH OF GROUND UNDER TEST.
C_2 IS CURRENT REFERENCE GROUND.
P_2 IS POTENTIAL REFERENCE GROUND.

the total circuit resistance. It is generally true that economies point toward rather large anode systems where pipeline systems are expected to operate over long periods of time and where fairly large currents are dissipated in medium to high resistance soils. It is evident that for low resistance soils and very small values of pipeline resistance to earth, the determining factor of the length of anode to use is mainly the one of service life.

Figure 9 shows the method of determining the resistance to earth of a structure.

It is pertinent to note that where ditching machines are used to dig trenches for ground beds, the cost per foot goes down with length, as

TABLE I

Location	Total Circuit Res. in Ohms		Diff. Calc. & Actual in Ohms	% Diff. Calc. & Actual	R_{PL} Ohms	R_T Ohms	$\frac{R_{PL}}{R_T}$ in Percent
	Calc.	Actual					
1.....	0.24	0.28	0.04	14.2	0.12	0.28	43
2.....	0.54	0.50	0.04	8.0	0.33	0.50	66
3.....	0.76	0.71	0.05	7.1	0.26	0.71	37
4.....	0.28	0.27	0.01	3.7	0.12	0.28	43
5.....	0.40	0.44	0.04	11.0	0.21	0.44	47
6.....	0.42	0.48	0.06	12.5	0.14	0.48	29
7.....	0.70	0.70	0	0	0.08	0.70	11
8.....	0.80	0.80	0	0	0.21	0.80	26

R_{PL}—Resistane of pipeline to earth, in Ohms.
R_T—Total circuit resistance, in Ohms.

the travelling time is the same whether a short or a long trench is dug.

Table I is a listing of some calculations of expected total circuit resistance compared to the actual total circuit resistance. It is seen that the differences vary between 0.0 and 14.2 percent. In these cases the resistance of the pipe to ground, R_{PL}, represents 11 to 66 percent of the total circuit resistance. Therefore, the R_{PL} offers practical limitations in the reduction of the total circuit resistance as, with an ever increasing length of anode, one can only approach a total circuit resistance equal to the pipeline resistance to earth, plus the wire resistance.

This then is one of the important features of the pipeline resistance to earth, for by knowing its value, as well as the other factors, for a certain location, the economical anode system may be determined.

Conclusions

In conclusion, it is believed that:

Great care and consideration should be given to the proper location and selection of anode systems for cathodic units.

Judicious care must be exercised in measuring soil resistivities for the location of anode systems.

Pipeline or sub-structure resistance-to-earth determinations are pertinent to the economical design of cathodic units.

In the design of an efficient anode system, the proper configuration should be selected, within the limitations of space and materials available.

Generally good correlation may be obtained between predetermination of total circuit resistance and actual circuit resistance of final installation of a cathodic unit. By this method, rectifier equipment for a cathodic unit may be ordered, with a reasonable degree of accuracy, ahead of the installation of the anode system, making due allowance for change of resistance with seasons.

It is realized that there are no set rules for establishing cathodic protection because there are so many variables and each case must be individually considered. In this light, the foregoing discussion has been presented with the hope that it may add to the sum total of previous statements of experiences and recommendations for establishing more efficient systems of cathodic protection.

Electrical Instruments and Measurements in Cathodic Protection*

By J. M. Pearson*

WHILE THE reader may not need to be introduced to cathodic protection and its problems, it is the author's conviction that each writer on the subject should state clearly the meaning of the terms he uses. In this way a reader whose ideas differ from those of the writer can be forewarned, he can better understand the meaning intended by the writer, and his criticism or use of the material will be more constructive. It is for clarity of expression rather than in the spirit of argument that the following definitions are set down:

Cathodic Protection: Reduction or control of the rate of corrosion of the surface of a metal in contact with an electrolyte by making that surface cathodic to the electrolyte by use of an impressed current.

Electrical Measurements: Measurements of physical quantities in standard units, using electrical methods, which fall into two categories:

1) Measurement of electrical quantities per se. (Such as volts, ohms, amperes, impedance, etc.)

2) Measurement of other than electrical quantities. (Such as temperature, pressure, corrosion rate, etc., by use of electrical means.

Electrical Instruments: Electrically operated devices including indicators whose readings are a direct measure of some physical quantity or are usable quantitatively to infer the desired measurement.

The problems of cathodic protection to which electrical measurements and instruments are usually applied fall into two general categories: Measurements to determine how much cathodic protection is needed and measurements to determine if a given installation is functioning according to design. Measurements for either purpose include determinations by direct indication and by inference.

It is the intention here to point out the state of the arts, "Electrical Instruments" and "Electrical Measurements," in cathodic protection work. It is not intended to imply that every job should be a monument of precision measurement, because in many cases there are less expensive alternatives. It is intended to point out the uses and limitations of techniques or instruments now in use, and to stimulate interest in tak-

★ A paper presented at the Annual Meeting of NACE in Chicago, Ill., April 7-10, 1947.

* Director of Physical Research and Development Laboratory, Sun Oil Company, Chester, Pa.

ing data, which may be significant in advancing the art.

Electrical Instruments

By far the most useful types of electrical instruments used in cathodic protection engineering are those depending on the D'Arsonval movement.[1] D'Arsonval indicators are used with arbitrary scales as null instruments with calibrated potentiometers. They are also used with calibrated scales to give the last significant figure in conjunction with calibrated potentiometers, and finally they are made with calibrations to read directly current, potential difference, resistance, etc.

In every case, the calibration of the meter or of the potentiometer-meter combination is made to read a current flowing in a standard shunt connected with leads of a specified resistance to the instrument; or it is made to read the potential difference existing at the terminals of the instrument or at the end of leads of specified resistance.

Errors of "Null" Potentiometers

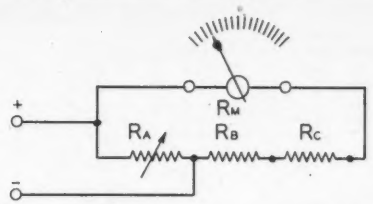
Repeatedly reference is heard about the use of a potentiometer "to eliminate the effects of lead resistance," and occasionally this misapprehension has resulted in a considerable instrument error. The important point is that every indicator draws some current from the circuit and if the current drawn produces a significant change in the circuit conditions, that change must be considered a correction to the instrument reading. For example, if a null-type potentiometer is used to measure the potential difference existing in a high-resistance circuit, and if the external resistance is equal to the internal resistance including the null indicator, the sensitivity of the latter is cut to one-half. For higher external resistances, which are not rare, the external circuit resistance directly controls the instrument sensitivity. Thus, if one division on the null indicator is equivalent to one unit of the potentiometer reading for low resistances, it may be that for high resistance circuits the null indicator will not indicate an error of five to ten units. It is thus quite possible that the "null" is so broad that the potentiometer reading cannot be trusted, especially where *differences* of successive readings are taken for use in engineering calculations.

Errors of Deflection Instruments

The comments above apply with even greater force to deflection-potentiometer readings and to readings of deflection type meters. In all cases it is necessary to account for the external circuit resistance, either to prove it insignificant by measurement or to determine the required instrument corrections.

One approach to the problem of errors arising from external circuit resistance is to use instruments of very high internal resistance so that external circuit resistances ordinarily encountered are negligible. Instruments with resistances from 20,000 ohms per volt up to 1,000,000 ohms per volt have been constructed and used. The difficulty with most of them is that temperature compensation of the movements is poor, and they are so delicate extreme care must be exercised in handling to avoid accidental damage. In addition, sensitive movements usually have a comparatively long period

This slows down the taking of data, and makes the comparison of simultaneous readings of two or more instruments less reliable when observations of transients are desired. The reliability of such simultaneous readings suffers severely if the conditions of damping of the two or more meters are not identical.



R_M = METER RESISTANCE, USUALLY WITH POSITIVE TEMPERATURE COEFFICIENT.

R_A = SHUNT RESISTANCE ELEMENT WITH ZERO TEMPERATURE COEFFICIENT.

R_B = SHUNT RESISTANCE ELEMENT WITH ZERO OR POSITIVE TEMPERATURE COEFFICIENT.

R_C = SHUNT RESISTANCE ELEMENT WITH NEGATIVE TEMPERATURE COEFFICIENT.

FIGURE 1
HIGH SENSITIVITY METER WITH COMPENSATING SHUNT

Damping and Compensation

With high sensitivity instruments, it is good practice to operate them with Ayreton type shunts designed to serve two purposes: first, to improve the temperature compensation; second, to make the damping slightly less than critical and substantially independent of the external circuit resistance. The first objective can be achieved by including properly designed elements with negative temperature coefficients of resistance. The second objective can be secured by adjusting the shunt so that the effective current sensitivity is about one-tenth the sensitivity of the movement, at a resistance a little higher than the critical damping resistance.

In Figure 1, R_A is usually made adjustable to secure the correct full-scale sensitivity of the shunted meter. R_B and R_C are adjusted so that $R_B + R_C + R_M$ have together a zero temperature coefficient of resistance. The value of $R_B + R_C + R_M$ is made a little higher than the critical damping resistance. These conditions are possible with movements (R_M) for which the external critical damping resistance is many times the value of R_M. Under such conditions, the shunted meter presents to the external circuit substantially the same loading resistance as would the movement alone, thus preserving the desired high ratio between internal and external circuit resistances. The instrument is temperature compensated and its damping is practically independent of external circuit resistance, at the expense of the use of a long time constant, rather delicate movement.

Electronic Instruments

Another approach to securing a high input resistance for indicating instruments is to use vacuum tubes between the input circuit and the movement of the indicator. In this way, effective input resistances of 10^9 ohms and upwards are practical, with the added advantage that relatively rugged indicators with short time constants are usable.

Instruments of this type fall into

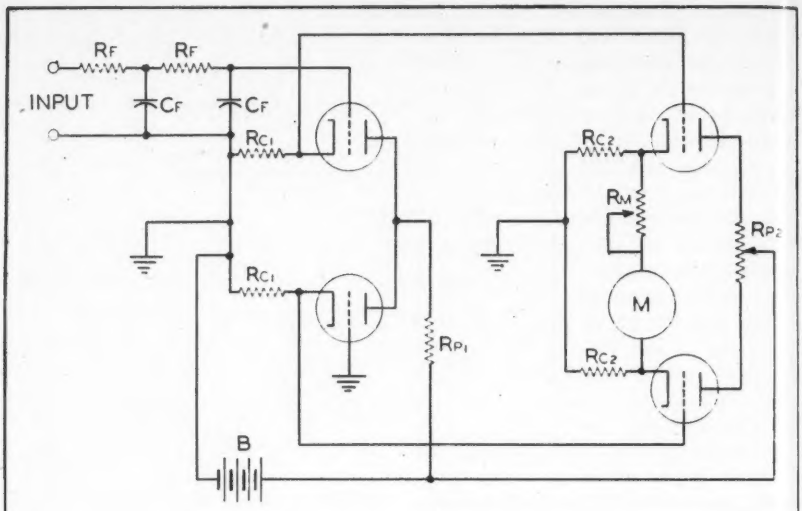


FIGURE 2
VACUUM TUBE VOLTMETER

two classes. In the first class are "vacuum tube voltmeters" in which the indicator, with its vacuum tube input, is calibrated as a unit, and the calibration includes any non-linearity introduced by the input circuit. In the second class, the indicator is an ordinary precision meter, preferably one of short period and rugged construction, driven by a negative feedback amplifier. The latter has the same action as a servo-mechanism except that it is all electrical and operates on an error signal which is the difference between the input voltage and the output voltage to the meter.

Figure 2 shows the diagram of a typical vacuum-tube voltmeter. (A commercial example of this type of instrument is the "Vomax" of McMurdo Silver.) It consists of two triode pairs each in push-pull and operating as cathode followers. The first pair uses high values of cathode resistors R_{C_1} and low potential between cathode and plate. This results in less ionization of residual gas in the tubes and hence in a very high grid impedance for the input. It also minimizes the grid current. The second pair of push-pull triodes operate at much higher potentials and currents, also as cathode followers to drive the indicator marked M. The push-pull arrangement serves to balance out variations in battery voltage and to compensate for contact potentials existing between tube elements. The potentiometer R_{P_2} is the zero adjustment, and the meter series resistance R_M is used to adjust the full-scale calibration.

This type of vacuum-type voltmeter is usually satisfactory from one volt full-scale range on up to

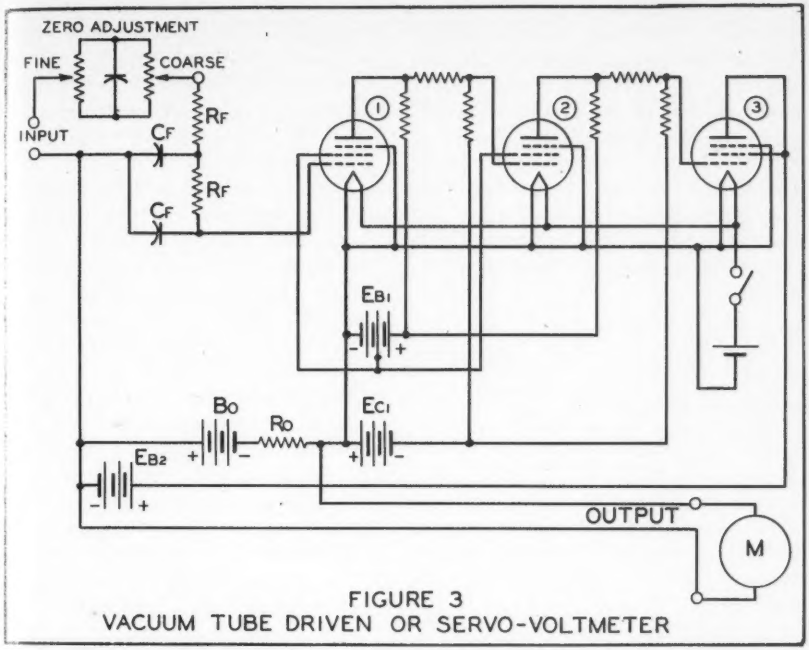


FIGURE 3
VACUUM TUBE DRIVEN OR SERVO-VOLTMETER

around ten volts. Above that, input voltage dividers are usually used. It has the advantage of excellent stability, but has the disadvantage that its range cannot be easily extended into the millivolt region; and the further disadvantage that any change in the transconductance of the tubes directly affects the calibration. In construction of this type of vacuum-tube voltmeter for field use, it is necessary either to use indirectly heated cathodes, which require a large filament supply, or use filament type tubes with four separate filament batteries. In either case, a filament supply of reasonably long life is likely to be bulky.

Any voltmeter using vacuum-tubes in the field is subject to errors due to stray a-c potentials. For this reason, instruments for use on d.c. should be fitted with input filters composed of elements such as R_F and C_F in the figure. The filter can be designed to have a high attenuation at frequencies of 25 cycles per second and up without materially slowing the response of the meter. The errors due to a.c. stem from the non-linearity of the vacuum-tubes and the resulting rectification.

Figure 3 is a diagram of a vacuum-tube driven or servo-voltmeter.[2] In this circuit the input to the first tube is the potential difference applied to the input terminals less the potential difference appearing across the output terminals and the meter M. This is so because the output circuit is between the cathode of the first tube and the lower input terminal. The operation is similar to that of a cathode follower except that the

cathode of the first tube is driven by current from the last tube. In this manner, the effective transconductance is that of the last tube multiplied by the total voltage amplification of the first two tubes. Any odd number of tubes can be used, for instance five instead of three, to secure the required transconductance. Ordinarily three stages are entirely practical.

If we let

G = effective transconductance, mhos
E_i = voltage at input terminals
E_o = voltage at meter terminals
M = meter resistance, ohms
E_g = voltage signal to input grid
i_p = change in plate current of last tube due to E_i

and if we adjust the zero with the input shorted so that the IR drop in R_o due to the plate current of the third tube just equals the battery voltage B_o, then when $E_i = O$ the meter will read zero. For $E_i \neq O$, the following condition obtains:

$$E_g = E_i - E_o$$

$$i_p = G E_g$$

$$E_o = \frac{M R_o}{M + R_o} i_p = \frac{M R_o}{M + R_o} G E_g$$

$$E_g = E_i - \frac{M R_o}{M + R_o} i_p = E_i - \frac{M R_o}{M + R_o} G E_g$$

$$E_g \left\{ 1 + G \frac{M R_o}{M + R_o} \right\} = E_i$$

$$E_g = \frac{E_i}{1 + \frac{M R_o}{M + R_o} G}$$

$$E_o = \frac{M R_o}{M + R_o} G E_g = \frac{E_i}{\frac{M + R_o}{G M R_o} + 1}$$

If $R_o >> M$, this is approximated by

$$E_o = \frac{E_i}{\frac{1}{GM} + 1}$$

From this it is apparent that when we make $GM >> 1$ the output can be made as nearly identical as the input as one desires. In other words, this type of circuit is the exact equivalent of operating the meter in series with an external circuit of $1/G$ ohms resistance; at the same time the input to the first tube is a circuit of extremely high d-c resistance, approximately the resistance of the input grid multiplied by the factor

$$\left\{ 1 + \frac{G M R_o}{M + R_o} \right\}$$

A word of caution in this respect: while the input resistance is high in the sense that a change of input voltage produces little change of input current, the grid current of the input tube is not necessarily zero. In circuits where currents of the order of 10^{-9} amperes are significant, the grid current should be accounted for.

Advantages, Disadvantages of Instrument

The advantage of this type of voltmeter drive is that, having once made the transconductance sufficiently high, variations in its value will have small or negligible effect in the meter readings. In addition, all that is needed to operate at millivolt levels is to connect a millivoltmeter to the output. For example, if 300 ohms per volt meters are used with a circuit of 3 ohms transconductance, the equivalent series resistance will be 1/3 ohm on all scales. This introduces errors as follows:

Range	*Error*	*Correction*
Volts	*Percent*	*Factor*
1.0	0.11	nil
0.1	1.1	1.010
0.01	11.1	1.11

Under most field conditions, correc-

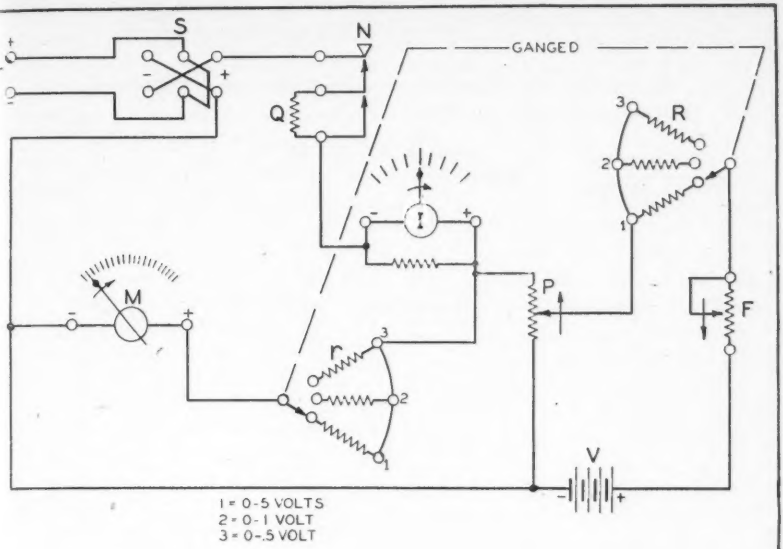


FIGURE 4
POTENTIOMETER-VOLTMETER INSTRUMENT

tions on the first two ranges can be neglected.

The disadvantage of this type of circuit is that it is subject to zero drift and must be regularly checked during a set of observations. Zero check switches can be arranged to make this operation quite rapid. Another disadvantage is a "noise level" of about 0.2 millivolts, which appears as random fluctuations on the lower ranges. Since the lowest range is usually of use as a null indicator, it is possible to operate in the presence of the noise level mentioned by switching the input on and off while watching the meter for any synchronous response.

In conjunction with indicators, a number of different circuit arrangements are used. When these circuits are designed to match a given indicator, and are arranged in a compact form for maximum ease of operation with minimum set-up time, they are quite properly referred to as instruments.

In Figure 4 is shown the circuit of a potentiometer-type voltmeter which has certain advantages for field use. It is intended to read structure to earth potentials in external circuits of 200 ohms resistance or less. The meter M is a high-grade voltmeter with ranges 0 - 5, 0 - 1, 0 - 0.5 volts on the range switch, at 1000 ohms per volt. The meter is driven by the potentiometer P of about 5000 ohms resistance, which is fed by the battery V in series with fine adjustment F and resistance R connected to the sliding contact. By connecting the potentiometer in this way, two advantages are secured:

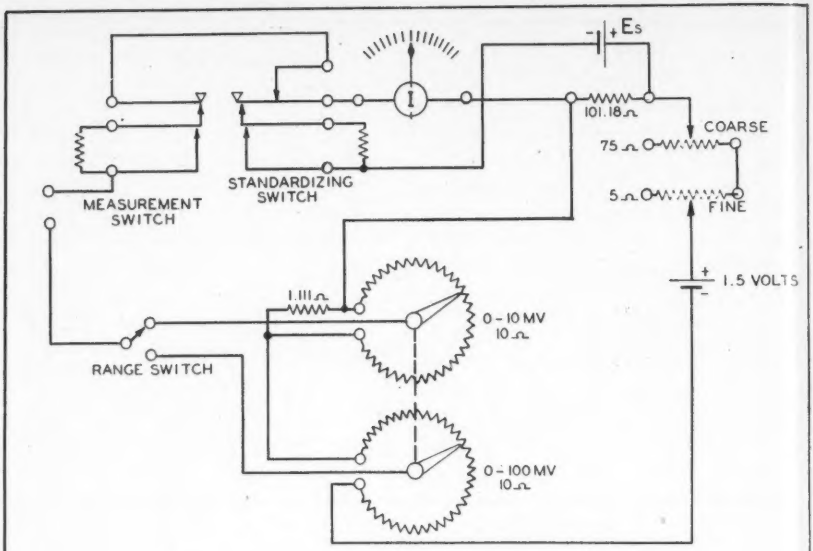


FIGURE 5
CALIBRATED POTENTIOMETER FOR MEASURING IR DROPS IN SHUNTS

The variations in contact resistance at the sliding contact, being in series with a relatively high resistance R, become less important. In addition the meter reading is exactly linear with the adjustment of the potentiometer P.[3]

The values of r for the three ranges will be chosen to maintain the 1000 ohms per volt sensitivity. The corresponding values of R are:

$$R_1 = 1300 \text{ ohms}$$
$$R_2 = 3000 \text{ ohms}$$
$$R_3 = 3400 \text{ ohms}$$

which provide for use of the full range of the potentiometer P with each range of the meter M. The fine adjustment F is a 500-ohm potentiometer, usually set at one-half range. V is a 9-volt battery.

If the indicator I has a resistance of about 1000 ohms, and the external circuit amounts to a maximum of 2000 ohms, to which we add a maximum of 2500 ohms for the meter and potentiometer, the indicator works in a circuit totalling 5500 ohms. In order to rely on the null point to one part in a thousand, the indicator must reliably indicate 5 millivolts of off-balance, or it must indicate a current of about 1.0 microampere. Thus a usable indicator would be one with a sensitivity not less than 10 microamperes per division with 1000 ohms internal resistance.

The reversing switch S allows reversed potentials to be read without reconnecting leads, and the null switch N connects the indicator to the external circuit to detect an unbalance. Q is a 50,000-ohm limiting resistance to protect the indicator when large off-balances are encountered.

Figure 5 is the circuit of a low-impedence potentiometer (see Leeds & Northrup Thermocouple Potentiometers) principally useful in measuring IR drops in a shunt or in a calibrated section of a structure. This instrument consists of two potentiometers of about 10 ohms resistance connected in series. One is shunted by 1.111 ohms so that the total resistance is 1.00 ohm. The series exciting circuit includes a 101.18 ohm standardizing resistance and a coarse and fine adjustment with a 1.5 volt dry cell.

The indicator must be able to detect about 0.01 millivolt unbalance in a 10-ohm circuit, which is a current of one microampere. The scale sensitivity of the indicator is thus about the same as that of the indicator used with the potentiometer-voltmeter combination, but because of the low resistance, in this case it is more difficult to obtain. However, sturdy galvanometers are available to meet both requirements.

Design for Field Use

Besides determining the desired accuracy, ease of operation, and convenience of set-up, the designer of an instrument should choose components which are able to withstand field use and effects of the weather. For example at points where variable contacts are used, corrosion is likely to cause trouble. The use of "wiping" contacts with sufficient contact pressure is generally good practice. Contacts of switches should be of fine silver because most of the corrosion products of silver are soft and easily broken through by the wiping action; the outstanding exception is silver sulfide, the removal of which often requires burnishing. Sliding contacts on potentiometer wires should be protected from moisture and dust, and the contact pressure made as high as is consistent with a usefully long life of the wire.

Pressure vs. Wiping Contacts

"Post office box" plug switches are inherently designed for high contact pressure and a wiping action, but are usually made of brass, bronze, or even of copper. All three metals produce strongly adhering corrosion products and field instruments with this type of switch should be systematically serviced to keep the contact resistance low.

It is good practice to enclose all variable contacts within the instrument case and to use felt or equivalent packing to exclude dust. Large current shunts which require ventilation or batteries which require periodic changes should be in separate compartments partitioned off from the instrument space. Bare, rigid wiring or wiring with resinous water-resistant insulation should be used. Rubber-covered wire or other sulfur-bearing material inside an instrument almost invariably leads to sulfided contacts and trouble.

Humidity

In tropical climates, instruments should be transported and stored in "dry boxes" when not in actual use. While this makes it possible to rely on most of the usual equipment, it is occasionally necessary to design instruments to include guard rings and dessicants to overcome leakage troubles.

The use of high voltage plate supplies with vacuum-tube instruments requires care to prevent leakage from the battery from causing trou-

ble at high-resistance points of the circuit. Plate supplies should be separated from ground and the instrument by insulation; and shielding placed so as to limit and conduct leakage back to the battery without involving part of the measuring circuit. Leakage of the wiring outside the plate supply can be minimized by using high-grade insulation and by locating sensitive parts of the circuit so that they are not easily involved with stray-leakage current.

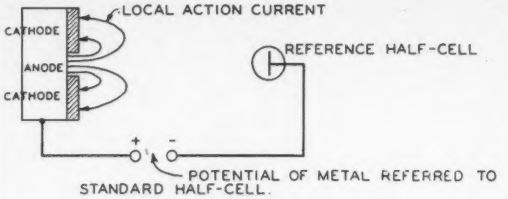


FIGURE 6
ELECTRODE POTENTIAL OF CORRODING METAL

Instrument Maintenance

Electrical instruments, in general, should be considered as tools, and should be designed to take punishment consistent with their use. Just as with tools, instruments too need servicing. A die could hardly be expected to cut perfect threads throughout its life without adjustment, and it is likewise unreasonable to expect a meter to read correctly throughout its life just because the correct calibration was originally marked on the dial.

One of the most usual reasons for loss of accuracy is loss of field strength in the air-gap of the movement. Modern magnetic materials make today's meters considerably more durable than their forerunners, but it is still good practice to equip a movement with an adjustable magnetic shunt, to allow for future resetting of the movement sensitivity.

Other common causes of inaccuracies are:

Bending of the needle so that when it is reset to traverse the scale, the coil no longer traverses the uniform part of the magnetic field.

Damage to the shunt or series resistors, or to the movement winding caused by excessive overloads.

Presence of dust or magnetic particles in the air-gap.

Cracked jewels or broken pivots.

When a meter movement is worn or damaged so that it sticks or will not repeat readings, or when it is no longer

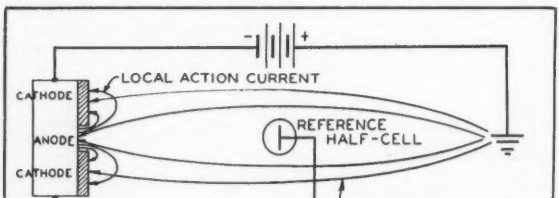


FIGURE 7
ELECTRODE POTENTIAL OF CORRODING METAL WITH IMPRESSED CURRENT

possible to make sensitivity adjustments, the instrument should be overhauled by the manufacturer. Generally, it is not very expensive to have an instrument restored to new condition.

Engineers interested in mechanical design may be surprised to learn that the design stress in the pivot resting on jewel bearings runs as high as 125,000 pounds per square inch. Little wonder that crushed pivot points and cracked jewels result from severe shocks. Occasionally pivots are bent by an overload, such as commonly bends a needle when it suddenly encounters the stop.

It is a wise investment to buy first-class measuring equipment and maintain it carefully, because in the field most of the time and effort is spent in getting to location and setting up to take data. If the instruments on hand at that time are inaccurate, or inoperative, the cost of the expedition may as well be written off.

It is also worthwhile to provide field personnel with proper means for transporting and protecting their instruments; for example pivot-type movements should be carried with their pivots horizontal and protected from dust and water in transit. Someone in each party should be responsible for regular inspections of equipment, checking of calibration, renewal of batteries, cleaning up after exposure to bad weather, etc.

Electrical Measurements

A great deal has been written about the engineering use of field measurements in cathodic protection, and details of engineering procedures and calculations are available in the literature. The balance of this article will be confined to fundamentals of measurement. No argument is presented on the relative merits of several engineering approaches to cathodic protection problems. Pointed out are reliable measurement techniques to secure the data upon which any engineering approach must rest.

Electrode Potential of a Corroding Structure

The electrode potential of a metal in an electrolyte is conveniently defined as the electromotive force (emf) between that metal and a reference half-cell under certain special conditions. These conditions are: that the half-cell is located outside the field of the local action currents, and that the effect of IR drops in the electrolyte between the metal and the reference cell as well as IR drops in the elec-

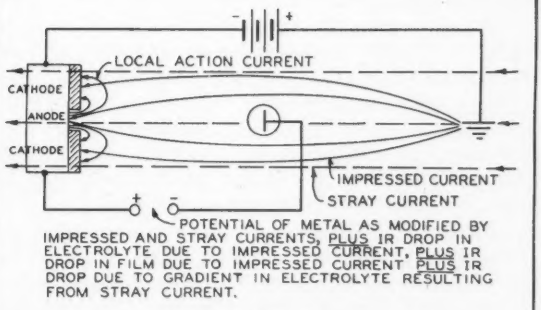
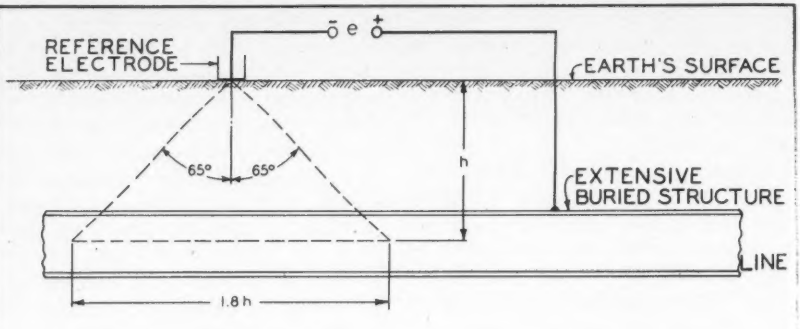

LOCAL ACTION CURRENT
CATHODE
ANODE
CATHODE
IMPRESSED CURRENT
STRAY CURRENT
POTENTIAL OF METAL AS MODIFIED BY IMPRESSED AND STRAY CURRENTS, PLUS IR DROP IN ELECTROLYTE DUE TO IMPRESSED CURRENT, PLUS IR DROP IN FILM DUE TO IMPRESSED CURRENT PLUS IR DROP DUE TO GRADIENT IN ELECTROLYTE RESULTING FROM STRAY CURRENT.

FIGURE 8
ELECTRODE POTENTIAL OF CORRODING METAL WITH IMPRESSED AND STRAY CURRENTS.



IN THE ABSENCE OF STRAY OR IMPRESSED CURRENTS, "e" IS THE SUM OF THE REFERENCE HALF-CELL POTENTIAL AND THE AVERAGE POTENTIAL OF THE SEGMENT OF STRUCTURE INDICATED; i.e. THE SEGMENT INDICATED ACCOUNTS FOR 90% OF THE OBSERVED STRUCTURE POTENTIAL.

FIGURE 9

ELECTRODE POTENTIAL OF EXTENSIVE BURIED STRUCTURE

trode film resistance are recognized and discounted.

Figure 6 represents an ideal case. A single, isolated metal electrode is located in an electrolyte in which nothing else exists but the reference half-cell. The reference cell is located outside the range of the local action currents, and the open-circuit emf between the two electrodes is termed the electrode potential referred to the half-cell chosen.

Figure 7 represents the same electrode in a more general condition encountered in cathodic protection, with an impressed current applied to it from an auxiliary circuit. In this case, the observed potential difference includes two IR drops algebraically added to the electrode potential desired. Because it is not unusual in regular field work to find IR drops two or three times the size of the actual shift in electrode potential, especially on new installations, unless the IR drop is measured and accounted for the potential difference measured is a most unreliable indication of the electrode potential.

Figure 8 is the extreme case, in which cathodic protection measurements are made in the presence of stray currents of significant magnitude. The stray currents do not necessarily involve the electrode of which the potential is sought, but they add another IR drop which may be significant in the total potential difference measured in the observing circuit. For structures that are not buried too deeply in the earth, advantage is taken of the fact that all stray currents near the surface must of necessity flow parallel to the surface. Thus by placing the observing half-cell directly over the structure being observed, the IR drops of stray currents are at right angles to the observing circuit, and their effects are usually negligible.

Measurements on extensive buried structures will not usually represent such simple cases as shown in

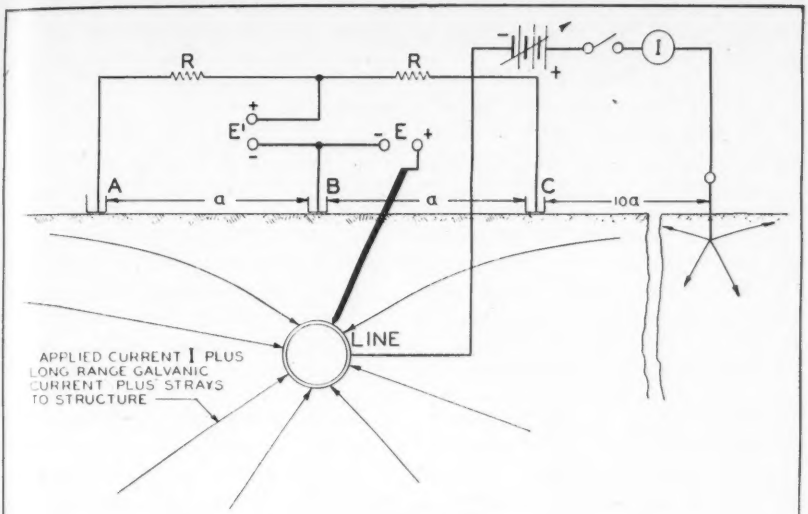


FIGURE 10
MEASUREMENT OF POLARIZATION BY IMPRESSED CURRENT

the last three figures. In the first place, cathodic protection is often applied to that part of a structure which is predominantly anodic. This means that in practice measurements are actually taken within the field of the local action current, part of which is flowing in large circuits to remote cathodes. In the second place, it is often the aim to provide protection to the anode (hot spot) without necessarily extending cathodic protection on the same scale to the rest of the structure, a condition dictated by economics in protection of bare structures.

These conditions make it desirable to explore the content of measurements usually taken, to be sure that adequate corrections are either included or proved to be negligible in fact. It is also desirable to know in advance the precision of measurement which the problem requires and how to decide that the data meet the requirements.

Measurements on Buried Structures

Figure 9 shows the amount of an extensive buried structure observed by a reference half-cell. The calculation is based on a bare structure, the film resistance of which is quite small, which is analytically equivalent to an electrostatic potential at the reference point due to a uniform line charge at the centerline of the structure. Under these conditions, 90 percent of the potential is determined by the indicated line segment, and the other 10 percent by all the rest of the line. It is apparent that detailed information of structure potential can be had only from finely detailed observations when the structure is bare, un-

less it is possible to take readings at suitably great distances in spite of the attendant difficulties.

A coated structure or one having a high surface resistance in place of the bare one of Figure 9 would yield a measurement which is integrated over a much greater segment. The measurement, by the same circumstance would be all the more subject to error from the several IR drops attributable to the impressed and stray currents not shown in the figure.

Measurement of Polarization

In Figure 10 is shown a method of measurement to determine the local electrode potential of the structure for different applied currents. Because of the long range galvanic currents and strays, this example includes measurements to account for their effect. Three reference cells of identical potential A, B, and C are arranged in a bridge circuit consisting of equal segments of earth "a" set off at right angles to the line and two equal resistances R so high that earth and half-cell resistances are small by comparison. By their dispositions, the gradient from A to B will equal and cancel the gradient from B to C, for stray currents transverse to the line. Consequently, such strays will not contribute to the potential difference, E′. The current flow lines indicated include those of the strays ending in the line, the galvanic current to remote parts of the line, and finally the impressed current I. Each of these causes a potential difference to arise between A and C on one hand and B on the other, thereby contributing to E′. From a study of the figure, it is apparent that if no current flow lines exist, E′ will read zero.

The potential difference "E" includes the IR drop between the reference cell B and the line and also the half-cell potentials of the surface of the line and cell B.

A measurement is made as follows: At any desired value of I, the value of E and E′ are accurately observed by use of instruments with any corrections necessary for the high measuring circuit resistance. The applied current is then changed to $I + i$ where i is about a 10 percent increment of test current. As a result of i, there will be observed increments of E and E′, which we will call e and e′ respectively. Since polarizations potentials vary slowly with the applied current, it is reasonable to assign the entire values of the potential increments to the results of IR drop. From this it follows that e/i represents the effective coupling resistance between the cell B and the line. This resistance includes the coating, the electrode film resistance, and the soil-path resistance, and the IR drop through it must be eliminated from E if we seek the real polarization potential of the line.

It was noted above that if E′ were zero, it would mean that no current flow existed between the line and earth. Since we have measured e′ which resulted from i, we can calculate the value of I which would just reduce E′ to zero by the ratio E′/e′ times i. When this calculation is made, let the result be I′. If I and I′ turn out to be the same, it is obvious that the galvanic and stray-current components are negligible, and all IR drops are due to the impressed current I. If I′ is greater than I, the galvanics and strays assist the impressed current, and if I′ is less than I, the galvanics and strays oppose

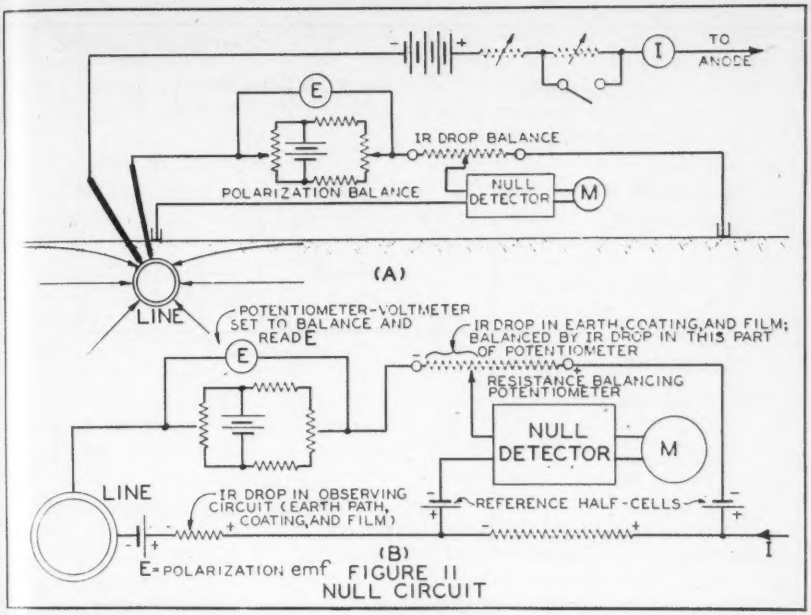


FIGURE 11
NULL CIRCUIT

the impressed current. In any case, the IR drop is the one corresponding to I′ and so the correction to E is minus I′e/i or minus $i \frac{E}{e'} \times \frac{e}{i}$. In this expression the value of i cancels out so the IR drop to be deduced is $E' \frac{e}{e'}$ It follows that the electrode potential of the line referred to B is

$$E - E' \frac{e}{e'} .$$

In using this method of correction it is important to remember that it is based on E′ being zero when no current enters or leaves the line. This will only be true if reference cells A, B, and C are all identical. On the other hand it is not necessary to know the exact value of i, since it cancels out, provided simultaneous values of e and e′ are used in the calculation. It is good practice to measure a series of simultaneous values of e and e′, and to use the average of their ratios for correction.

Reference Cells

At this point it may be well to note a difficulty sometimes encountered when using reference cells such as the copper sulphate "pot." When reading on dry earth, an engineer will sometimes pour water on the surface to lower his circuit resistance before placing his electrode. This occasionally leads to an error which results from the electrokinetic potential of the water flowing into the dry earth. It is better to dig down to moist earth in which the fluids are at rest to secure a good reading.

When the bridge circuit of Figure 10 is used as an earth-current meter, it is common to observe that the

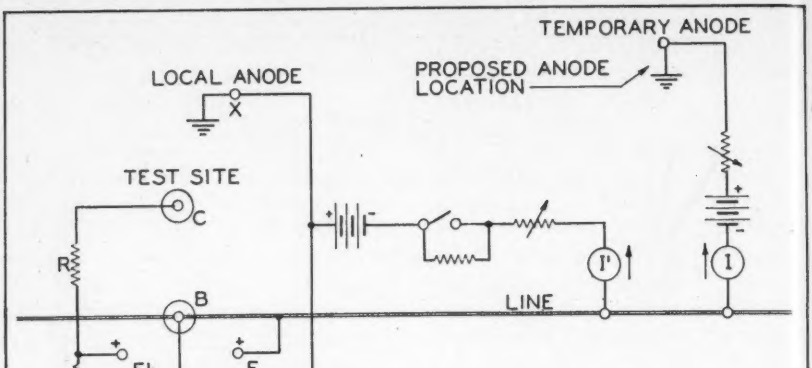


FIGURE 12
APPLICATION OF TEST CURRENTS

transverse currents are a minor source of potential gradient compared to the gradients near the line attributed to the currents interchanged between the line and earth. The principal exceptions are found in the vicinity of other grounded structures which are sources or sinks of current. In view of this practical fact it is possible in the large majority of cases to simplify the measurement of polarization in two ways: A bridge circuit can be designed to balance out the IR drops directly and because of the symmetry of the flow lines near the line half of the bridge in Figure 10 can be omitted.

In Figure 11, (A) shows the null circuit[8] in which the IR drop in a high resistance potentiometer is balanced against the IR drop in the earth, line coating, and electrode film. Also in Figure 11, (B) is an equivalent circuit in which the two pairs of balanced elements of (A) juxtaposed for comparison. In (B), if the potentiometer-voltmeter is adjusted for the value E, and if the IR drop in the resistance balancing potentiometer is adjusted to match the IR drop between the null detector and the pipe, the null detector will read zero. Since a small variation of the impressed current will not materially affect the value of E, an increment of I (about 10 percent) can be used to test the resistance balance. Several such tests are usually necessary to set the balance, and correspond to the increments used in the previous circuit to determine the IR drop correction. The difference in this case is that the IR drop is compensated out of the reading instead of corrected for in the null circuit.

The complete theory of the null circuit and discussion of its use has been published before and need not be repeated here in detail.

Direct vs. Inferred Data

At the beginning of this article, electrical instruments and electrical measurements were defined from two standpoints, namely measurement by direct readings and measurements from which the quantities are inferred. The two methods just outlined for determining the polarization of a buried structure illustrate the difference between the two standpoints. In the first method, polarization plus IR drop are included together in the instrument indications; it is therefore necessary to take additional data to determine the IR drop and thus infer the value of the polarization. In the second method, the IR drop is compensated directly by the instrument making the observation, so that when it is adjusted, the reading is the desired polarization. The advantages of using direct reading methods are the saving of time required to take multiple data, and the avoidance of error associated with calculations to infer the desired values. The disadvantages are the increased complexity of the test equipment, with the requirement that the operators clearly understand their use and are aware of circumstances which may lead to inaccuracies.

Application of Test Currents

In the preceding discussion, the measurement of polarization as a function of the applied current was mentioned without specifying the source of the current. In practice, the greatest part of the cost of a cathodic protection installation is the cost of the circuit and power source to apply the protective current. It may seem from this that the cost of running tests might be comparable to the cost of applying protection, making the former an impractical consideration.

Anode Location

In many cases the location of the anode is determined by the location of permanently wet earth, by the question of avoiding interference with other structures, or by the availability of right-of-way. An engineer with previous experience in the territory can estimate within reasonable limits the required size of the anode, so that it is often economically feasible to install the anode prior to making tests.

In certain other cases there may be a critical choice to be made between several anode locations, and preliminary tests are needed to decide the choice. It is possible in these cases to use local anodes near the test site and to relate those measurements to the effects of current actually to be expected from the true anode location.

Test Anodes

Figure 12 shows the arrangement for making such measurements. In the figure, a test anode is located at the site of the proposed anode location. Its resistance will usually be too high to permit polarization runs to be made except perhaps in its immediate vicinity. At the remote point of interest, a measuring set up as in Figure 10 is used, and shown in plan in Figure 12. In addition, two local anodes X and Y are placed in the

axis of the bridge at a distance from the line of about five times the spacing of B-C or B-A. Because these anodes are close to the part of the line under test, the current density they apply to that part is correspondingly high; the result is that a considerably lower test current can be used. If we can make our measurements with I′ and then reduce them to terms of the desired current I, we have secured polarization data without the use of the heavy currents normally necessary. To do this, we run the polarization curve either with the earth-current meter correction or by using the null circuit, by impressing the test current through X and Y. We next reduce the value of I′ and adjust it so that with a higher value of I the potential difference at the earth-current meter E′ is exactly the same with I′ on and I off and vice versa. Let us designate this the current ratio I/I′. Since the electrodes A, B, and C are in the vicinity of the line where the flow-lines are practically radial, the reading of E′ is proportional to the current per foot interchanged between line and ground. Hence the polarization data taken with various values of I′ when multiplied by the above ratio I/I′ will be the data desired, i.e., the current required at the remote anode location to polarize the structure at the test site.

The validity of the test procedure outlined depends on current flow substantially perpendicular to the structure in its immediate vicinity. This is accurately true for bare structures, or for structures with uniformly leaky coatings. For the better coatings which leak only at widely spaced faults, the test procedure is certainly not valid; however, for that type of good coating, the current requirements are so small that satisfactory tests can usually be made with the temporary anode.

As a final thought on the use of electrical instruments and measurements in cathodic protection engineering, we might remark that in the last analysis the data taken is of inferential value only. Having secured the electrical measurements with the minimum of expense and error, they are still not the final answer. The answer lies in the test of the final installation, the fitness of which will testify to the care and competence of the engineer.

REFERENCES

1. Standard Handbook for Electrical Engineers, Seventh Edition, Section 3.
2. Pearson, J. M., Null Methods Applied to Corrosion Measurements, Trans. Electrochem. Soc., **81**, 485-508 (1942).
3. Ewing, Scott, Soil Corrosion and Pipe Protection, AGA (1938).

Surface Studies of Metals From the Corrosion Standpoint

*By M. G. Fontana**

MOST OF THE WORK described in this article was carried out under a fundamental corrosion research project sponsored by the Office of Naval Research.** The general theme of the project concerns a study of surface films formed on metals at normal and elevated temperatures. The data reported have been obtained within the last year. The studies are by no means complete, and much work remains to be done. This article should be regarded as a progress report and the conclusions as tentative.

Passivation of 18-8S Stainless Steel

One of the problems under active study is the nature and mechanism of passivity of stainless steel, or why does stainless steel corrode or not corrode? The excellent corrosion resistance of the stainless steels is usually attributed to passivation of the surfaces of these materials. A passive surface is one that exhibits "noble" characteristics or practical immunity to attack by corrosive environments as compared to the substantial corrosion that occurs on an active surface. In other words, a passive alloy shows much better corrosion resistance than the electromotive series positions of the constituent elements would indicate. For example, the position of chromium in the emf series indicates poor corrosion resistance, yet chromium is the major element contributing to the corrosion-resistant properties of the stainless steels. It should be emphasized that passivation is a relative term—an alloy may be passive to one environment, but it may be violently reactive to another corrosive medium.

Several explanations have been advanced concerning the nature and mechanism of passivity of stainless steels. The most widely accepted theory postulates the formation of an oxide, such as chromium oxide, on the surface of the metal and this oxide protects the metal from corrosion. Another theory assumes that chemically adsorbed oxygen forms a protective layer on the metal surface. However, little or no proof has been found to substantiate and, accordingly, to promote the definite acceptance of these theories.

* Professor of Metallurgical Research and Director of the Corrosion Research Laboratory, The Ohio State University, Columbus, Ohio.

** Contract with The Ohio State Research Foundation. Investigation carried out in the Engineering Experiment Station.

The research on which this article is based, indicates that 18-8S (AISI Type 304) stainless steel becomes passive because of a physically adsorbed gas. At room temperatures, specimens of this alloy display passivity upon exposure to air and lose passivity upon exposure to reduced pressure (vacuum). This process is reversible in that the alloy can be passivated, broken down, re-passivated, and so on, by alternate exposure to air, vacuum, etc. The ready breakdown of the passivity under vacuum at room temperature indicates weak bonds between the gas and the metal, which in turn indicates physical adsorption. Oxides or chemisorbed gases would be considerably harder to remove or break down and this would probably require the use of an elevated temperature.

No attempt is made here to explain the many "peculiar" behaviors of stainless steels in actual services or in corrosion investigations. Remarks apply directly to the corroison media studied. It is hoped that this report on the results of our work will encourage and stimulate research by other investigators in this field. Our study is being continued.

Passivation Treatments and Corrosion Tests

Several passivation treatments were tried during the preliminary phases of this study. The treatment found most effective, based on corrosion tests, we shall designate here as "sulfuric-air" treatment. It consists of exposing a specimen of 18-8S to boiling 10 percent sulfuric acid for three minutes, washing thoroughly in water, and then exposing the specimen to air. Removal by corrosion of a small amount of metal from the alloy, followed by exposure to air, was found to be an effective passivation treatment by the author several years ago. (Incidentally, this situation accounts for many of the apparent inconsistencies in the data resulting from corrosion tests on stainless steels and stainless alloys in sulfuric acid and other media.) Specimens of 18-8SMo (Type 316) passivated by this method showed no discoloration or corrosion by plant rayon acid bath for 3000 hours, whereas untreated specimens turned black and corroded within 24 hours.

Recent tests on treatment with hot hydrochloric acid and hot acetic acid, followed by exposure to air, also results in passivation. Apparently, all that is required is removal of a small amount of surface metal by corrosion. The hydrochloric acid method appears to be more desirable than the treatment with sulfuric acid, because a cleaner surface results. Water washing is not necessary in the case of hydrochloric acid, and a rinse in acetone is sufficient. Specimens washed in acetone and not exposed to air remain active.

Arbitrarily, we prefer to regard "air-passivation" as the true passivation of stainless steel. This alloy can be protected from corrosion by the formation of surface coatings, such as corrosion products, by inhibitors and, to take an extreme case, by painting.

Treated specimens are tested for corrosion resistance by complete immersion in 10 percent sulfuric acid and synthetic ocean water at 50° C.

Sulfuric acid is selected because it rapidly corrodes an active specimen and is practically harmless if the specimen is passive. This test is a good "yardstick" by which to determine in a short time the performance of the specimen. The synthetic ocean water is prepared according to direction given in Naval Research Laboratory Report P-2909, by T. P. May and C. E. Black. Another reason for the selection of these media is that the acid results in uniform corrosion, or general attack, and the sea water results in the localized or pitting form of corrosion.

To clarify the procedures used, it is emphasized that sulfuric acid is used to treat the specimen *prior* to exposure to air (passivation), and also to determine the corrosion resistance of the 18-8S after passivation.

Several sources of supply of Type 304 stainless steel were used during this investigation. Most of the work, however, was carried out on ¼-inch by 2-inch bar stock with the following composition: 0.05 percent carbon, 18.86 percent chromium, 9.08 percent nickel, 0.05 percent molybdenum, 0.35 percent silicon, 1.12 percent manganese, 0.024 percent sulfur and 0.016 percent phosphorus.

Test Schedule

A photograph of the vacuum breakdown apparatus is shown in Figure 1, and a schematic diagram in Figure 2. (Because the results obtained indicate a promising field for further research, improved equipment is being assembled, including a more sensitive McCleod gage, a mercury diffusion pump with higher capacity, and a better vacuum pump for the exhaust from the mercury pump.)

The procedure in the tests already made is briefly as follows:

1) Fill the acid reservoir and tube to and including stopcock F (Figure 2) with 10 percent sulfuric acid; clean tubing below F, and also the specimen flask with acetone and dry thoroughly;

2) Seal the specimen flask to the vacuum system with a cement;

3) Evacuate the system to stopcock E;

4) Place the passivated specimen in the flask, insert ground-glass stopper and evacuate; the system from the diffusion pump to F is now under high vacuum;

5) At the end of the vacuum period, close E and open F, thus bleeding in acid to cover the specimen without exposure to air;

6) Open G to atmosphere, break vacuum seal by heating cement (joint previously brought up to atmospheric pressure through A and C), and transfer the flask containing the specimen to the constant temperature bath for corrosion test;

7) For repassivation or exposure to air, argon or other gases, close E and open G after the end of the vacuum period.

Numerous "control" specimens were run in this equipment. In these cases, the specimens were handled in exactly the same manner, except

that the flask was not evacuated, or it was evacuated for only a brief period. In all of these cases, the specimens remained passive.

Time of Exposure to Air

A series of runs were made to determine the effect of the time the specimens were exposed to air on passivation. Specimens treated in hot sulfuric acid, washed and weighed in 10 percent sulfuric acid and then transferred to the corrosion test without exposure to air, remained active. Specimens exposed to air for only a few minutes showed passive characteristics. Since the weight losses on passive specimens are low (approximately within the accuracy of the weighing technique), the data are not suitable for plotting the time of exposure to air versus the corrosion rate. There may be differences in the stability, or effectiveness of the passivity developed on different specimens, but a reliable method for determining these differences has not yet been developed. The break-through potential apparatus may be suitable for this purpose. Attempts are also being made to determine the exact time at which passivity breaks down during the corrosion tests, since this point could be used to differentiate the stability of various surfaces.

The specimens subjected to vacuum treatments were all passivated by exposing to air for 30 minutes or one hour. The above tests indicate that these times are sufficiently long to insure the development of a passive surface.

Practically all of the corrosion tests reported here consist of one 48-hour period. Results obtained on subsequent periods are of little value, because the first period of the corrosion test is similar to the passivation treatment used. In other words, if corrosion occurs during the first period, the specimens tend to become passive while exposed to air during the washing and weighing to determine the weight loss for the first period. Anyone with experience in the corrosion testing of stainless alloys in sulfuric acid is probably

TABLE I

Vacuum Breakdown of Passivation

(Passivation treatment: Boiling 10% H_2SO_4 for 3 minutes, washed and then exposed to air).

Specimen Designation	Pressure mm. Hg.	Time Under Vacuum Hrs.	Behavior in Corrosion Test*		Remarks
			Surface	Corrosion Rate Mils per Year	
1 (Many)	None	None	Passive	0	
2	0.001	1.5	Active	278	
3	0.001	6.0	Active	280	
4	0.002	1.8	Passive	0	
5	0.002	2.0	Passive	0	
6	0.002	3.2	Passive	0	
7	0.002	4.5	Active	N.D.†	Corrosion started immediately.
8	0.002	6.3	Active	N.D.	Corrosion started immediately.
9	0.002	7.0	Active	N.D.	Corrosion started immediately.
10	0.002	18.0	Active	N.D.	Corrosion started immediately
11	0.002	24.0	Active	N.D.	Corrosion started immediately.
12	0.06	6	Passive	0	
13	0.13	75	Borderline	N.D.	Broke down slowly, then corroded.
14	0.2	24	Passive	N.D.	

* 10 percent H_2SO_4 at 50° C. † Not determined.

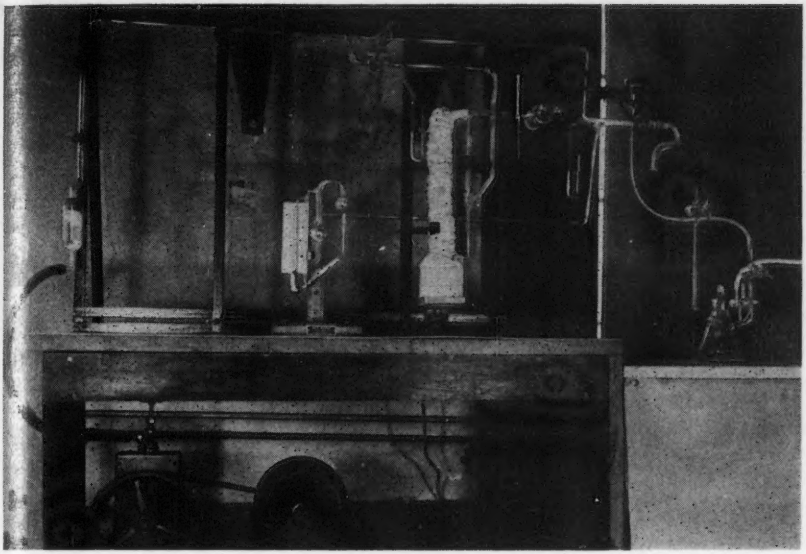


Figure 1—Apparatus for vacuum breakdown of passive surfaces.

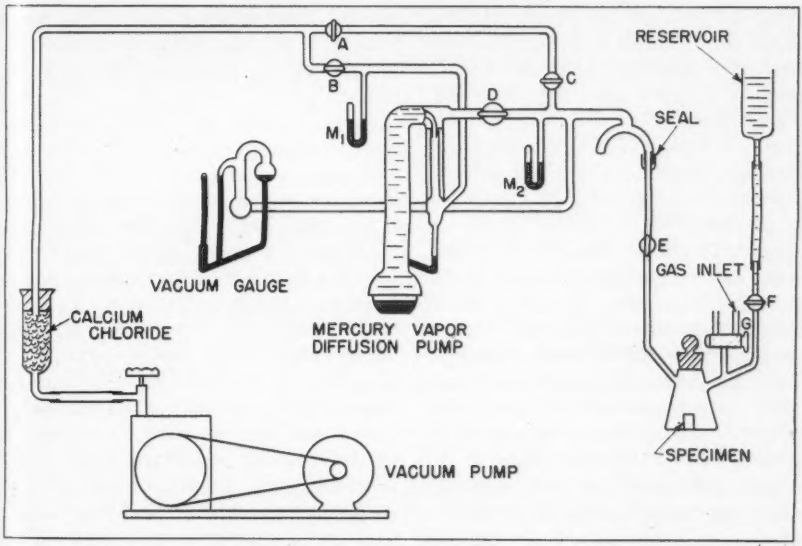


Figure 2—Diagram for vacuum breakdown apparatus.

TABLE II

Results of Cyclic Tests

(Specimens exposed to air after breakdown of passivation by vacuum treatment.)

Specimen Designation	Vacuum Treatment		Time Exposed To Air After Vacuum Treatment	Surface
	Pressure mm. Hg.	Time Hrs.		
1.....	..0.0005	6	1 hour	Passive
2.....	0.001	6	5 minutes	Passive
3.....	0.001	6	30 minutes	Passive
4.....	..0.0005	50	30 minutes	Passive
5.....	..0.0005	50	30 minutes	*
5a.....	..0.005	6	none	Active

* Not subjected to corrosion test, but continued as Run No. 5a. No. 4 and 5 run simultaneously. No. 4 removed and tested for corrosion resistance, but No. 5 again broken down by vacuum treatment (see 5a).

familiar with this phenomenon and the supposedly erratic results often obtained.

Effect of Pressure

Table I shows some of the results obtained during this investigation. Specimens 2 and 3 indicate that passivity is destroyed after 1.5 hours under a pressure of 0.001 mm. Specimens 4 through 11 show that a longer time (about four hours) is required for breakdown at the higher pressure of 0.002 mm. Specimens 12, 13 and 14 also show that the time for breakdown increases as the pressure increases. Perhaps there is a critical pressure above which breakdown of the passive film would not occur.

Table II shows results of experiments where the passive film is destroyed by vacuum treatment and then the specimens are again made passive by a subsequent exposure to air. Based on the results in Table I and numerous similar tests, the six-hour exposure to vacuum assures breakdown of the passive film.

With a little experience, one can readily tell whether the specimen is active or passive by observing the action on the metal for a few minutes after the acid is bled into the specimen flask. In most cases, however, the specimens are subjected to an actual corrosion test.

Hydrogen in the Metal

One possible objection to the adsorbed gas theory for passivation is that gas (hydrogen) may be removed from the metal while it is in the vacuum, thus rupturing or destroying the passive film. The mechanism could be described as follows:

Hydrogen enters the metal as a result of the boiling three percent sulfuric acid pretreatment. Now assume that a chemisorbed layer or an actual oxide layer is formed on the metal surface during its exposure to air. When the specimen is exposed to a vacuum, the hydrogen is drawn out of the metal and on its way out, it ruptures the chemisorbed layer or surface oxide and thus destroys passivity. Re-exposure to air then merely heals the ruptured areas by re-forming the chemisorbed layer or oxide.

Runs No. 4, 5 and 5a in Table II, were designed to check this point. If hydrogen destroys passivity in 1.5 hours or less at a pressure of 0.001 mm. (See Table I), the hydrogen must have a fairly strong tendency to leave the metal under these conditions. Accordingly, 50 hours at less than 0.0005 mm. pressure should remove a substantial amount, and perhaps all of the hydrogen. Run 4 shows that the surface whose passivity was destroyed by treatment for 50 hours at less than 0.0005 mm. pressure, again becomes passive as a result of exposure to air for 30 minutes. Assuming that all of the hydrogen in the metal is removed by the

50-hour treatment, then the re-passivated surface should not break down upon subsequent vacuum treatment if the objection under consideration is valid. Run 5a in Table II, shows that this is not the case, because the surface becomes active again during the six-hour vacuum exposure.

This experiment is not conclusive, however, since there is no definite assurance that *all* of the hydrogen in the metal is removed by the 50-hour, low-pressure treatment. Further work on this aspect is in progress with regard to (a) treatment at elevated temperatures and high vacuum to remove hydrogen, (b) acid methods, such as electro-polishing, to activate the specimens without allowing hydrogen pickup, and (c) other methods not involving acids for activating the metal surfaces.

Synthetic Ocean Water

Table III shows the results of tests in synthetic ocean water on 18-8S specimens with different "passivation" treatments. It will be noted that the sulfuric-air treatment is the only one which prevents pitting of the alloy. In connection with Run No. 6 numerous corrosion tests were also made in sulfuric acid on 18-8S heated in air at temperatures in the range 225-870° C., to form oxide coatings. None of these coatings are protective in this acid.

Argon

Preliminary tests using cylinder argon gas (nominally 99.8 percent argon, 0.2 percent nitrogen) "purified" by passing the gas over hot calcium metal to remove oxygen, and a P_2O_5 (phosphorus pentoxide) tower to remove water vapor, showed that argon passivated 18-8S. "Spectroscopic" argon was obtained later, but gave erratic results as to passivation. If conclusive evidence could be obtained that 18-8S passivates in argon, this information would be very strong and definite support for the physically adsorbed gas theory proposed herein, since this gas is very inert chemically.

TABLE III
Corrosion of 18-8S by Synthetic Ocean Water at 50° C.
(Heavy metals added. pH 8.2)

Specimen	Passivation Treatment	Pits
1	None	Many
2	Boiling 3 percent H_2SO_4 3 minutes; air ½ hour	None
3	Fuming HNO_3, 1 hr at room temperature	Many
4	30 percent HNO_3 +0.5 percent $K_2Cr_2O_7$, 1 hr at 60° C.	Many
5	10 percent $K_2Cr_2O_7$, 1 hr at 60° C.	Many
6	Air at 870° C. for 1 hour	Large

All of the argon tests were made on specimens the surface passivation of which had previously been broken down by vacuum exposure, except for one attempt to passivate directly with argon after activation in boiling acid. Passivation was obtained, but the experimental procedure is open to question.

Electron Diffraction

Passivated 18-8S surfaces were extensively investigated in an attempt to find oxides such as Cr_2O_3 (chromium oxide). Electron diffraction patterns gave no evidence of their existence, and these experiments are considered to be indirect evidence that passivity is not due to crystalline oxides on the surface of the metal.

Polished with 120 emery paper following the usual procedure for preparing corrosion test coupons, 18-8S is not passive to sulfuric acid.

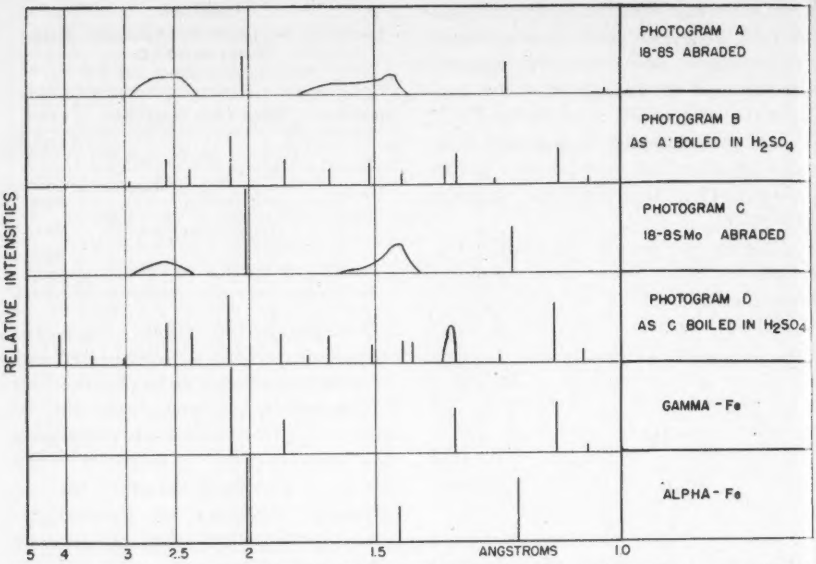


Figure 3—Graphical representation of electron-diffraction data for surface films on passivated stainless steel.

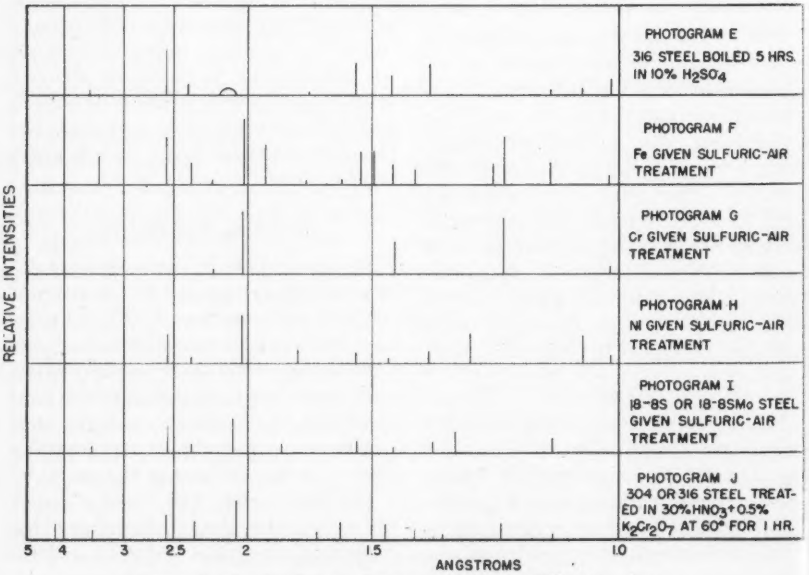

PHOTOGRAM E
316 STEEL BOILED 5 HRS. IN 10% H_2SO_4
PHOTOGRAM F
Fe GIVEN SULFURIC-AIR TREATMENT
PHOTOGRAM G
Cr GIVEN SULFURIC-AIR TREATMENT
PHOTOGRAM H
Ni GIVEN SULFURIC-AIR TREATMENT
PHOTOGRAM I
18-8S OR 18-8SMo STEEL GIVEN SULFURIC-AIR TREATMENT
PHOTOGRAM J
304 OR 316 STEEL TREATED IN 30% HNO_3 + 0.5% $K_2Cr_2O_7$ AT 60° FOR 1 HR.
RELATIVE INTENSITIES
5 4 3 2.5 2 1.5 1.0
ANGSTROMS

Figure 4—Graphical representation of electron-diffraction data.

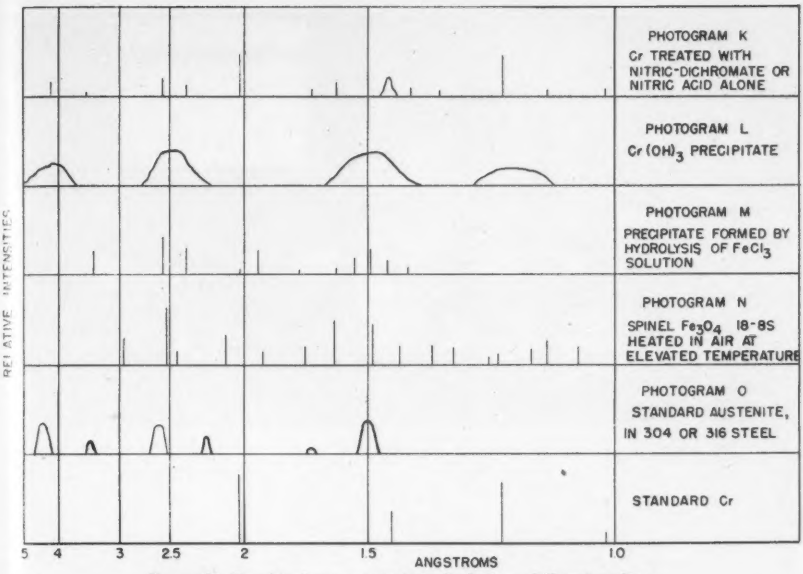


Figure 5—Graphical representation of electron-diffraction data.

Perhaps the cold-worked surface due to polishing, or the surface layers formed because of slight heating during polishing, inhibit the formation of an adsorbed gas layer. In addition, the removal of polishing scratches during the boiling sulfuric acid treatment, perhaps forms a better base surface for the adsorbed gas layer.

The electron diffraction photographs show an alpha iron pattern (See Photograms A and C, Figure 3), on polished specimens, and gamma iron on the surfaces treated in boiling 10 percent sulfuric acid for three minutes (see Photograms B and D). Gamma iron and alpha iron photograms are included in Figure 3

Figure 6—Reproduction of electron-diffraction photograph from which Photogram G of Figure 4 was produced.

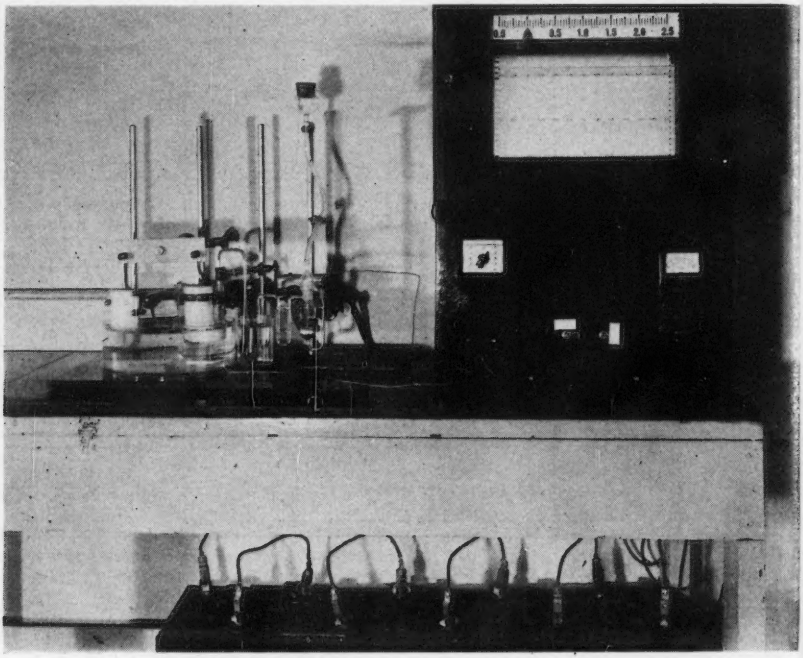


Figure 7—Break-through potential equipment for studying metal surfaces.

for comparison. The small amount of corrosion that occurs during the acid treatment is sufficient to remove the cold-worked metal surface layer (alpha iron) formed during polishing. There is the possibility that gamma iron is more capable of adsorbing gas than alpha iron. This possibility will be further explored through the use of ferritic 18-8 material.

The photograms shown are a plot of relative intensities versus spacings of the diffraction maxima in angstrom units. The photograms are a convenient and working method of presenting the data, because most of the electron diffraction photographs would be somewhat difficult to reproduce in printing.

Photograms F, G, and H, were obtained from iron, chromium and nickel, respectively, which had been given the sulfuric-air treatment. Photogram F has been identified as iron plus a hydrated iron oxide of unknown composition, but typical of surface films found on iron subjected to submerged corrosion in acid solutions. Photogram G has been identified as metallic chromium plus one unidentified diffraction line at 2.21A (angstrom units). Photogram H is the pattern of nickel plus an unidentified "corrosion film" which corresponds to Photogram E, which is the pattern produced by

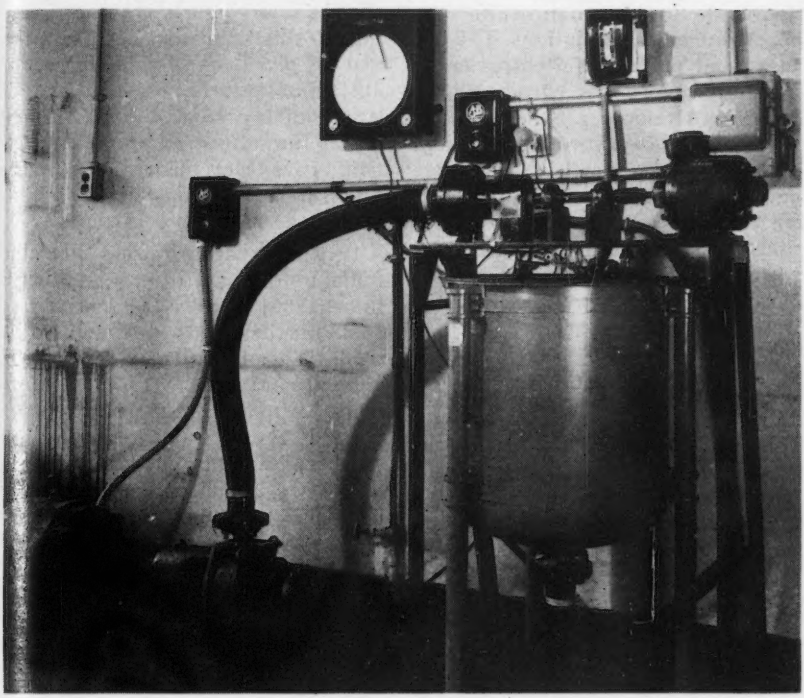


Figure 8—Equipment for testing the erosion-corrosion resistance of materials.

the sulfuric-air treatment. The electron diffraction photograph used to produce Photogram G is shown as Figure 6.

Photogram I was obtained on 18-8S and 18-8SMo given the sulfuric-air treatment. This photogram shows the pattern of austenite plus the corrosion film represented by Photogram E. Photogram J shows a ferrite pattern (cold-worked layer not dissolved) plus the corrosion film produced by the nitric-dichromate treatment. This "corrosion film," or that portion of Photogram J not accounted for by the ferrite pattern, has not been identified, but it does correspond to the corrosion film produced on metallic chromium given the nitric-dichromate or nitric treatment (Photogram K in Figure 5). Iron and nickel treated with nitric-dichromate solution showed the same pattern as the sulfuric-air treatment (Photograms F and H).

Since the above electron diffraction data indicates the presence of hydrous oxides on the metal surfaces, attempts were made to examine by electron diffraction several synthetized hydrous oxides. Photogram L was obtained from a precipitate formed by adding ammonium

hydroxide to chromium sulfate or chromium acetate solutions. The diffuse band pattern in Photogram H is due to amorphous chromium hydroxide. Attempts are being made to synthesize hydrous chromium oxide having a particle size large enough to give sharp electron diffraction patterns. Photogram M, obtained from a precipitate formed by hydrolysis of ferric chloride, bears a close resemblance to the hydrated iron oxide of Photogram F.

Other Treatments

Specimens of 18-8S treated with boiling hydrochloric acid and air were also examined. The patterns obtained were similar to that shown by hydrous iron oxide commonly found on iron samples after submerged corrosion in acid solutions, (Photogram F).

Specimens of 18-8S boiled in water for 36 hours and then exposed to air became passive. Photogram O resulted from this treatment. Electropolished 18-8S was also passive and this treatment is being studied further.

On the basis of the foregoing, it is believed that considerable evidence is available that the corrosion products are some form of hydrous oxide similar to rust on iron. The same type of hydrous oxide is formed, regardless of the base metal or the anions in contact with it.

Nickel Hydroxide

The ASTM Index of Standard Patterns was searched, but failed to show agreement with any compound the possible presence of which would be suspected from consideration of the chemistry involved. One exception to this statement occurs in the case of nickel hydroxide, the x-ray diffraction pattern of which is similar to the "corrosion film" formed during the sulfuric-air treatment. Attempts are being made to synthesize nickel hydroxide for direct comparison of the respective patterns.

Because hydrated oxides are also found on ordinary iron, it is difficult to attribute entirely the passivity of 18-8S to the presence of a hydrous oxide. This hydrous oxide is probably present on the 18-8S prior to exposure to air, but the air exposure is necessary to produce passivation —otherwise, the specimens remain active. It is quite likely that the hydrous oxide is of material assistance, or forms a good surface, in the physical absorption of gas to produce passivity. The specimens boiled in water for 36 hours indicate that this is a possibility. Other corrosion products on the surface of the metal could function in a similar capacity.

The specimens that were heated in air as described, gave beautiful electron diffraction photographs indicating the presence of crystalline oxides, as expected. (Photogram N).

Future Studies

In addition to the studies suggested, investigations on the effect of other fluids, such as nitrogen, oxygen, hydrogen, water vapor and water, on 18-8S and other types of stainless steels are in progress.

The stability of the passive films is also being studied by means of break-through potentials and erosion-corrosion, but this work has not progressed sufficiently at present to

warrant further description or discussion. The equipment for these tests is shown in Figures 7 and 8. Passivated by the sulfuric-air method, 18-8S shows a breakdown potential of approximately 0.6 volt. Straight chromium steel (Type 410) similarly treated, gave a breakdown potential of 0.07 volt.

Passivation with Nitric Acid

Passivation of stainless steel equipment by exposure to warm dilute nitric acid is quite common practice in industry. Numerous tests here using this passivation treatment does not passivate stainless steel. This treatment is a fruitless operation, and a waste of money as far as passivation benefits are concerned. More and more corrosion investigators are adopting this viewpoint. The nitric acid treatment may be of some benefit in removing iron particles that may have been imbedded in the surface of the metal during rolling, but this is not a passivation effect; if the metal is pickled after rolling, which is often the procedure, the nitric acid treatment is a superfluous operation. The usual mill operation of pickling should be considerably more effective than the nitric acid treatment, by the fabricator or user, as far as passivation is concerned. Pickling doubtless dissolves some of the metal surface, and the pickling operation is normally followed by washing and exposure to air. In other words, a commercial pickling operation is somewhat similar to the sulfuric-air passivation treatment used in the work described.

Adsorbed Gas

The author believes that this investigation presents strong evidence to support the proposed theory that passivation of 18-8S is due to a *physically* adsorbed gas. This gas is attached to the metal surface by van der Waal's forces, and these forces represent poor adherence or weak bonding. Elementary text books on physical chemistry state that gases held by these forces can be removed by evacuation. On the other hand, chemically adsorbed gases cannot be removed by evacuation, according to the literature. Chromium oxide is, of course, a stable compound that does not break down under low pressures at room temperature.

High Temperature Oxidation

Preliminary tests on 18-8S at 1800° F. in dry mixtures of oxygen and nitrogen, show that the oxides or scale formed in an atmosphere of low oxygen (five percent) is more protective than scale formed in high oxygen (95 percent), based on subsequent exposure to a 20 percent oxygen atmosphere.

Acknowledgement

The electron diffraction studies were carried out by Messrs. Nelson, Schwartz and Vaughan of the Battelle Memorial Institute. The corrosion work was largely done by Messrs. Beck and McCullough, graduate students at the Ohio State University. The efforts of all of these gentlemen is hereby gratefully acknowledged. The interest and support of these investigations by the Office of Naval Research is greatly appreciated.

Regalvanizing of Welded Joints

*By George H. Ohmer**

GALVANIZED STRUCTURES and sheets from which the original galvanizing is burned off during the welding process are successfully regalvanized on the job with a low melting zinc base alloy to prevent rust and corrosion. This method of regalvanizing can be applied to seams made by arc or gas welding and to other galvanized areas that have been worn or damaged. In welding, the intense heat of the arc or flame burns off the coating of zinc and exposes the bare metal adjacent to the weld. In most cases, it has been impractical to regalvanize the bare spots by the hot-dip method which requires a heated receptacle containing molten zinc, and which is impossible in the case of large structures.

This process of regalvanizing is quite simple. In its barest essentials, the process consists of "tinning" the weld area with a stick of the low melting regalvanizing alloy to form thereon a new coating, which will have all the appearances of the original coating together with the corrosion resisting properties and wearing qualities of zinc.

In actual practice, if the weld is made with bare rod, as in the case of oxy-acetylene welding, the weld is wire brushed immediately after welding to remove surface oxides. Then a bar of the low-melting alloy is rubbed over the surface while it is still hot to fix a deposit of the galvanizing alloy, and while this alloy remains in a liquid state, the wire brush is used to smooth the alloy evenly over the entire area to be regalvanized.

Although this galvanizing alloy can be applied by using the residual heat of the weld, regalvanizing can be done at any time by simply reheating the area to be regalvanized to approximately 600° F. The alloy itself begins to melt at 445° F., and is completely fluid at 460° F. Thus there is no danger of burning the zinc coating upon reheating as ordinary hot-dip galvanizing does not burn at temperatures under 900° F.

An interesting feature is the fact that where there is enough heat to damage the original galvanizing, there is also sufficient heat to regalvanize with the low-melting alloy. It was further discovered that the melting temperature of the residual heat extends fully as far from the actual position of the weld as the outside edges of the bare spots. The importance of this is apparent when it is considered that the bare spots may extend as much as 1½ to 2 inches from the position of the weld, thus leaving considerable area subject to immediate corrosion and rust if not protected.

* Chief Engineer, Galv-Weld Products, Dayton, Ohio.

It has been found that no deleterious effects will be produced at the welds and bare spots which may develop during welding will be left with a galvanized coating. The coating, by actual U. S. Navy Yard tests during the war, was found to be not only as good, but actually superior to the original coating insofar as toughness, long wear, quality and appearance are concerned. One such test is described below:

Object of Test

(a) The object of this test was to determine the suitability of the low-melting, galvanizing alloy in effecting the repair of galvanized surfaces damaged during welding of zinc coated high tensile steel, by comparison with similar repairs made using the zinc metal spray method.

(b) For test purposes, specimens were cut from black uncoated No. 20 titanium treated manganese (MnTi) and manganese vanadium (MnVa) high tensile steel plates.

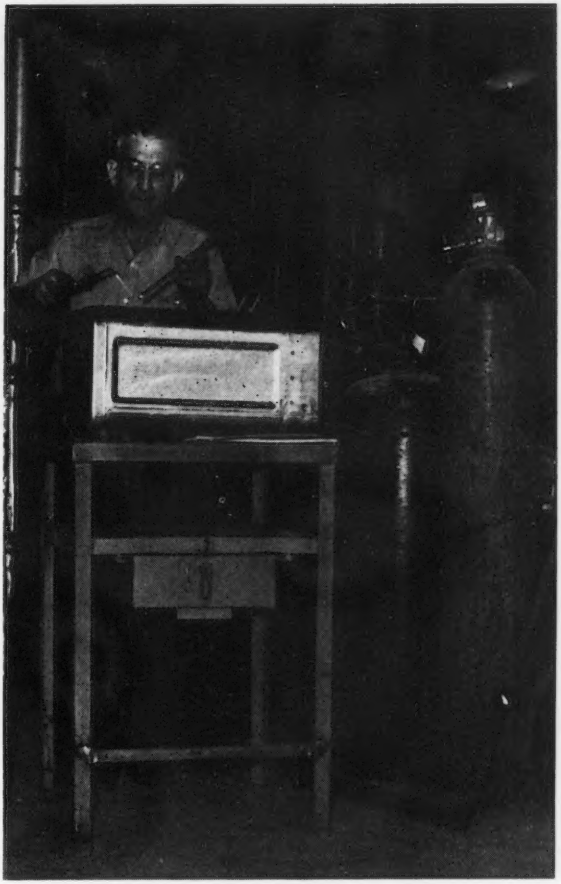


Figure 1—Repairing skips and blemishes in hot-dip galvanized surfaces on metal boxes with Galv-Weld Alloy. Operator is using oxy-acetylene torch to heat metal surface to approximately 600° F.

Method of Test

(a) Hot bend tests were made on specimens of black MnTi, and MnVa high tensile steel after coating with low melting regalvanizing alloy and the results compared with those obtained for galvanized and zinc metal spray coated specimens.

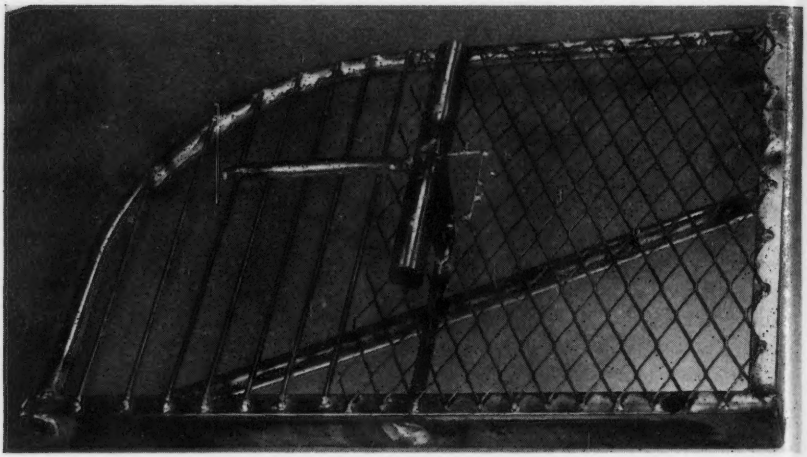


Figure 2—Radar screen, showing welded joints coated with Galv-Weld to avoid electrolysis at joint.

(b) Cold bend tests were made using galvanized specimens representing both plate materials after heating up to 1350° F. in an electric muffle furnace to represent damaged zinc coating. The coating on one-half the number of specimens of each plate material was repaired with the regalvanizing alloy while hot, and after cooling to room temperature, all specimens were bent to 180 degrees and examined for cracks.

(c) In order to simulate conditions that may be encountered in the coating of stressed material in the field, specimens from the MnTi high tensile steel plate of known yield strength were stressed as simple beams in a special jig. These specimens were centrally loaded until the tension in the outer fibera approximated the yield stress of the material, as determined by an extensometer. In this stressed condition, the tension face of the specimens was coated with the regalvanizing alloy using an acetylene torch. After cooling, the specimens were examined for cracks.

(d) To simulate the repair of galvanized plate surfaces after welding, standard 12-inch tensile steel specimens of each material, after galvanizing were placed in a tensile machine and stressed to approximately 26,600 pounds per square inch (20,000 pounds load). While in this stressed condition, a one-quarter inch single bead weld was deposited transversely on every third specimen and longitudinally on the remaining specimens. One-third of the number of specimens of each material, in each welded condition, were stressed to 60,000

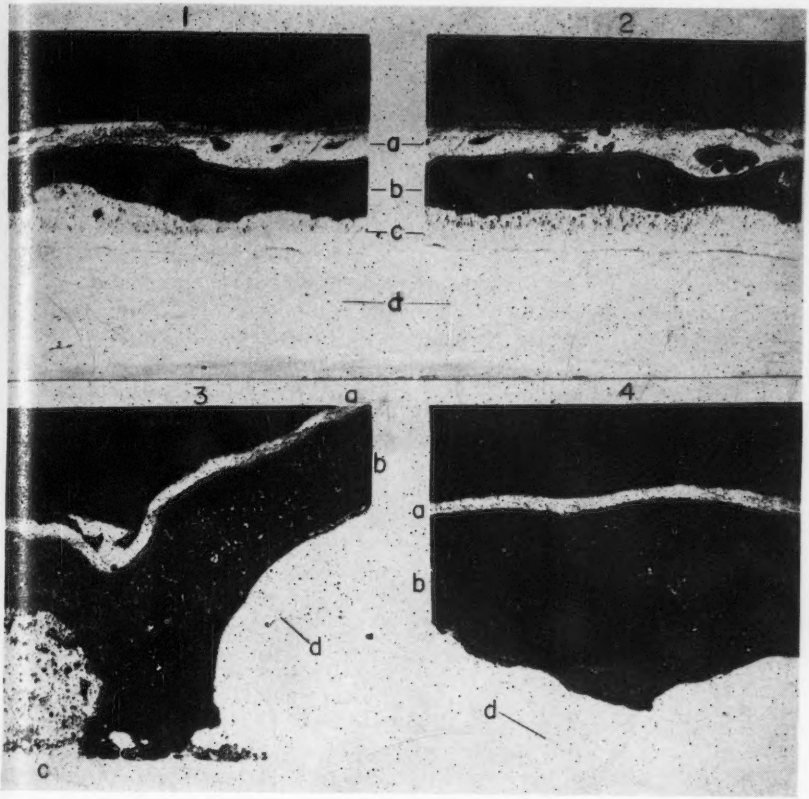
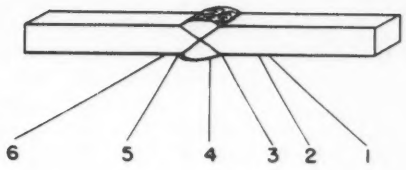


Figure 3—Microstructure at 100 diameters (reduced about one-half in reproduction) of a cross-section of galvanized sheet showing a treated butt-weld joint. In order to avoid damaging the alloy coating while polishing the cross-sectional surfaces, the specimens were copper plated.



SKETCH SHOWING LOCATION OF PHOTOMICROGRAPHS

a-COPPER PLATE
b-DROSS
c-GALV-WELD
d-BASE METAL (STEEL)

psi without further treatment, immediately after welding. The load was released and the specimens examined for cracks.

(e) One-half of the remaining tensile specimens of each material in each welded condition were zinc metal sprayed while under stress, and the remainder coated with the regalvanizing alloy by heating to approximately 600° F. with an oxy-acetylene torch. After being coated, the stress in each specimen was increased to 60,000 psi, released, and the specimens examined for cracks.

(f) Following the above test, all tensile specimens were placed in the tensile machine and loaded to failure, and the surface of each specimen again examined for cracks.

Result of Tests

(a) Space does not permit tabulation of the test results but a comparison of the low melting galvanizing alloy coatings with zinc metal sprayed coatings indicates that, insofar as bonding to the base metal is concerned, the regalvanizing alloy coating is superior. There was no tendency of the galvanizing alloy to flake off the material when the specimens were bent or otherwise stressed beyond the elastic limit.

(b) A review of the test results indicates that the galvanizing alloy has no embrittling effect on MnVa and MnTi high tensile steel during application or at elevated temperatures after application. Furthermore, satisfactory repairs to damaged galvanized surfaces can be effected without detriment to the base metal.

Photomicrographs show that the new galvanized coating is strictly a continuous layer with no holes or fissures therein, and a 141-day salt spray test, or 17 times longer than that required of hot-dip galvanizing for government approval, indicated the absence of rust or corrosion of the galvanized coating.

Prior to the war, this regalvanizing process was used only in connection with the welding of large outdoor metal sign frames, where it was found that by welded galvanized construction as versus conventional bolted methods, less steel was used and freedom from vibration and corrosion was obtained. During the war, the process was used throughout the shipbuilding industry for both commercial and fighting ships; commercial use today finds this galvanizing alloy in many industries, not only for new construction but in the maintenance and protection of older equipment where the original galvanizing has been worn or damaged. This process allows the full use of mill supplied galvanized sheet, shapes and pipe for the construction of all-welded galvanized structures.

Cathodic Protection of Hot Water Tanks*

*By J. M. Bialosky**

EVERY GALVANIC CORROSION cell in a conducting solution may be represented by Figure 1. The anode reaction is $M \rightarrow M^+ + e$, and the electron charge "e" is transferred through the metallic path to the cathode, where it results in the cathodic reaction $H^+ + e \rightarrow H$ or $\frac{1}{2} O_2 + 2e + H_2O \rightarrow 2OH^-$.

As these reactions proceed at the metal-liquid interphase, the film of liquid in immediate contact with the anode becomes more concentrated with respect to the metal ion. This results in a change in the potential of the anode in accordance with the Nernst equation. This change in potential of the anode is the anode polarization. The equilibrium potential depends upon the current flowing and the diffusion characteristics of the metal ion in the solution. The latter may vary with the ionic concentration of the body of the solution with respect to the film temperature, and the rate of flow of the liquid over the surface which controls the thickness of the film. The anode polarization is also dependent upon the presence of ions which will form complex radicals or precipitates with the metal ion.

At the cathode, the reduced hydrogen acts as a hydrogen electrode, and with the reduction of the hydrogen ion concentration of the cathode film, the potential of the cathode changes. Another cathodic reaction, which occurs in solutions containing dissolved oxygen, is the reduction of oxygen to hydroxyl ions which reduces the hydrogen ion concentration of the cathode film. This change in potential of the cathode is the cathode polarization. The dynamic equilibrium potential of the cathode is dependent upon the current density, the diffusion of hydrogen through the liquid and the metal, the hydrogen overvoltage of the cathode, diffusion of oxygen

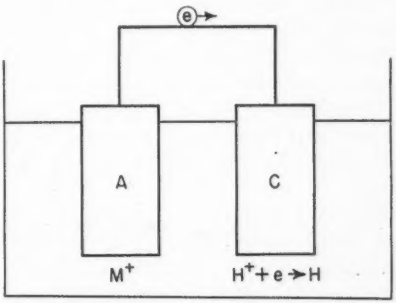


Figure 1

★ A paper presented at the Annual Meeting of NACE in Chicago, Ill., April 7-10, 1947.

* Formerly Associate Metallurgist, Armour Research Foundation, Chicago, Ill., now associate with Carnegie-Illinois Steel Corp., Research Laboratories, Pittsburgh, Pa.

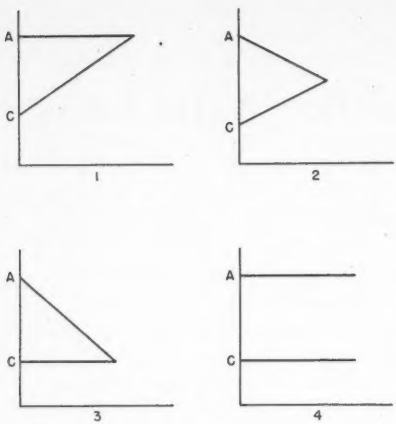


Figure 2

to the liquid-metal interphase, and precipitation of dissolved solids due to change of pH.

In the theoretical galvanic couple described, there are four possible types of polarization reactions. These are as follows:

1) Cathode polarization, or cathode control.
2) Anode and cathode polarization—mixed control.
3) Anode polarization, or anode control.
4) No appreciable polarization of either anode or cathode.

These four conditions are shown in Figure 2.

Cathode polarization is the normal type reaction which controls the corrosion of steel, zinc, copper, and other metals in water. Anode polarization controls the corrosion of stainless steel and many metals in aqueous solutions containing chromate inhibitors. The last case where no appreciable polarization of the anode or cathode occurs is standard practice for all primary cells, but to be avoided, of course, in corrosion cells.

Cathodic Protection

Cathodic protection of a couple may be obtained by use of an auxiliary galvanic anode or by the application of an external potential with an insoluble or expendable electrode.

The action is shown in Figure 3. The left side of the drawing shows the theoretical corrosion couple previously described. When the circuit is closed to produce cathodic protection of the couple, electrons flow from the battery and are discharged at the cathode where they result in an increase in polarization of the cathode.

This polarization reduces the potential difference between the cathode and the local anode and thereby reduces the local cell corrosion current. When the applied current density is sufficient to eliminate the potential difference between the local anodes and cathodes, protection is obtained. The point should be emphasized that although reference is most often made to the protective current density required for protection, the point at which protection is fully achieved is determined by the potentials of the local anodic and cathodic areas. It is obvious that the polarization is the result of the current but the mitigation of corrosion is not due to the applied current per se. The applied current is, therefore, not equal to the internal corrosion current which may be calculated from weight loss measurements.

The theoretical action of cathodic protection is shown graphically in

Figure 4. For the moment we will consider the anodic and cathodic areas to be equal. In the diagram, A and C represent the anode and cathode open circuit potentials and M the normal corroding potential of the couple at the normal current represented by D. As the potential of the couple is made more negative (by means of an external source) to some potential F, the anodic current is reduced to a value G and the cathodic current increased to a value H. When the potential of the couple is reduced to A, the anodic current is reduced to zero, and the cathodic current is represented by J. At more negative potentials, the original anode may function as a cathode, and its cathodic polarization curve may be represented by line AR. At any value equal to or more negative than A, all corrosion of the anode is prevented and protection is obtained.

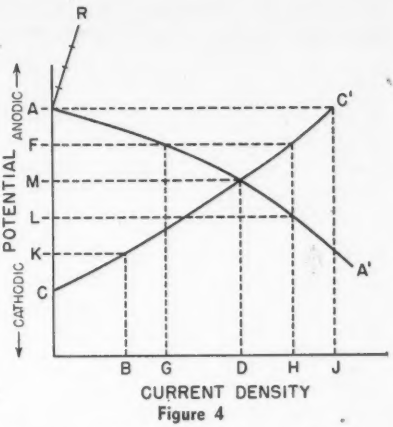


Figure 4

Corrosion of Commercial Metals

In actual practice, a commercial metal may be considered to have a multiplicity of local anodes and cathodes and be, in effect, a number of corrosion couples. The causes of local corrosion current have been discussed by R. B. Mears and R. H. Brown[1] who enumerate seventeen possible causes. The potential of a piece of a real metal against a solution is actually the resultant polarized potentials of the local anodes and cathodes of the freely corroding metal.[2]

Up to this point, the anode and cathode areas and current densities have been assumed to be equal. In the actual corrosion of a piece of metal, anode and cathode areas are seldom, if ever, equal. The pitting of metal is an example of a limited anodic area. Referring again to Figure 4, when the cathode area is large compared to the local anode, the low cathodic current density may be represented by point B and the high anodic current density by J. If the corroding medium is water having a high resistivity or which deposits a

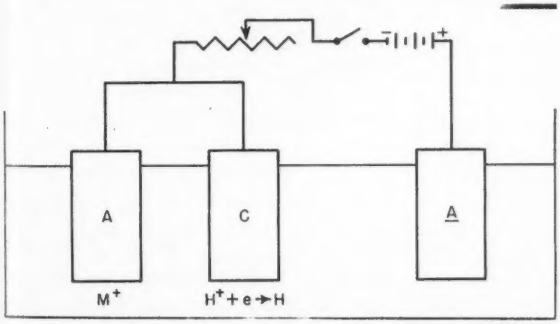


Figure 3

TABLE I

Ions Which May Be Present in Potable Water

Cations		Anions	
Calcium,	Ca^{++}	Carbonate,	CO_3^{--}
Magnesium,	Mg^{++}	Bicarbonate,	HCO_3^-
Sodium,	Na^+	Chloride,	Cl^-
Potassium,	K^+	Sulphate,	SO_4^{--}
Ferric iron,	Fe^{+++}	Nitrate,	NO_3^-
Aluminum,	Al^{+++}		
Manganese,	Mn^{++}		

high resistance film of calcium or magnesium hydroxides or carbonates, then the complete elimination of the potential difference between the anodes and cathodes is not required for complete protection. To demonstrate this condition, assume that the IR drop is represented by AF. In this case, it is only necessary to polarize the cathode to potential F in order to achieve complete protection.

The theoretical curves for anode and cathode polarization have been presented to explain the action of cathodic protection. However, it should be noted that the true measurements of the areas involved in the anodic and cathodic reactions and accurate determination of the local potentials are not readily accomplished in the case of commercial metals.

The numerous anodes and cathodes present on a metal surface immersed in water may vary widely in their specific polarization reactions. Brown and Mears[3] have reported an ingenious method of measuring the current and potentials of anodic and cathodic areas in their fundamental discussion of cathodic protection.

Consider for a moment the problem of corrosion in hot water. The water supplied to the heater contains some dissolved mineral hardness, which may consist of any of the anions and cations shown in Table I.

The important point to keep in mind is that calcium and magnesium, which are present as the soluble bicarbonates, are converted to the insoluble carbonates or hydroxide upon heating or upon raising the pH of the water. When corrosion occurs under water, the pH of the cathode film is increased due to the reduction of H^+ ions to H_2 or O_2 to OH^- ion. Since the pH rises in the film of liquid in contact with the cathodic surfaces and results in a precipitation of the slightly soluble carbonates and hydroxides, this method has been suggested as a means of softening water.[4,5] However, our interest in this film lies in the fact that precipitated solids act as a blocking layer, which retards diffusion of oxygen to the surface and thereby reduces the current density requirements for cathodic protection. Another effect of the applied potential is the migration of positively charged colloidal silica and hydroxides of aluminum, magnesium, and iron to the cathode, where they may be discharged and occluded in the cathode film. The precipitation of magnesium salts on the surface of a tank having a magnesium anode may have given rise to the erroneous statement that magnesium is plated on the inner surface of the tank by the electric current.

Conductivity of Water

The importance of the conductivity of the water should not be overlooked, since this characteristic affects the local corrosion cell current and possibly the area of the local cathode. The conductivity of the

water is roughly proportional to the concentration of the dissolved solids. It has been suggested[6] that the degree of protection obtained with galvanic anodes in galvanized hot water tanks will be a function of the conductivity rather than the hardness of the water.

Protection of Hot Water Tanks

The application of cathodic protection to hot water tanks follows the fundamental principals described in the foregoing material. Insoluble or expendable anodes with suitable rectifers are used for larger industrial tanks. Several installations have been described in the literature[7, 8, 9] covering tanks with capacities ranging from 30 to 1400 gallons.

Open tanks permit the escape of gases which are liberated from the water upon heating, and these installations require lower current densities than closed systems. If insoluble anodes are used, of if excessive current is used with soluble anodes, oxygen is liberated, this oxygen can escape in open tanks, but may lead to difficulties in closed systems if the oxygen is carried into the system and results in concentration corrosion cells at some points remote from the tank. When soluble anodes are properly used, no oxygen is evolved, but the corrosion products of the anode enter the water and may increase the hardness. If the corrosion products are undesirable in the water, the anodes may be bagged similar to the practice in electroplating.

A number of materials have been used as soluble anodes including stainless steel, carbon steel, and aluminum, while graphite has been used as an insoluble anode. A recent report[10] indicates that aluminum alloy anodes appear to be the most suitable material because the corrosion products do not discolor the water and the anodes corrode quite uniformly.

The Dow Chemical Company and several water heater manufacturers have been conducting tests with magnesium anodes to cathodically protect galvanized hot water storage tanks. As a result of this work, several manufacturers are now marketing their heaters with magnesium electrodes, and one is offering anodes of various sizes for installation in any home heater or range boiler.[11] From laboratory and service tests, it is claimed that the

TABLE II

Factors in the Design of Cathodic Protection Installation for Hot Water Tanks

I. **Water**
   - A. Chemical analysis
   - B. pH
   - C. Dissolved oxygen
   - D. Conductance

II. **Operating Conditions**
   - A. Ambient Temperature
   - B. Flow rate
   - C. Type of heating
     1. External coils
     2. Internal coils

III. **Anodes**
   - A. Galvanic anodes
     1. Anode composition
     2. Number of anodes and geometrical distribution.
   - B. Rectifiers
     1. Anode composition
     2. Number of anodes and geometrical distribution.
     3. Voltage and amperage required to maintain protective current density.

anode life will be from 5 to 15 years, and may be replaced at the end of its service period. The time interval will depend on the character of the water and the operating conditions, but protection will be afforded to the tank as long as sufficient anode is present.

The initial potential of a galvanic anode is fixed by its chemical composition and may be altered by polarization. The current output from this type of electrode may be decreased with time by the increase in resistance resulting from the loss of cross-section. In the domestic water heater tank protected with magnesium, the reduction of current flow caused by cathodic polarization tends to precede and mask the decrease in current flow which would be expected to attend the reduction in anode cross-section.[12] The current output from a galvanic anode may be controlled at any value below the maximum by the use of a series resistor. This method of control is incorporated on one domestic hot water heater[13] now on the market.

The correct application of cathodic protection to hot water tanks will successfully combat corrosion. There are a number of factors which must be carefully considered in the design and engineering of these installations. These are summarized in Table II.

We have attempted to present the theory of cathodic protection and some of the specific factors which are involved in hot water tank protection. The problems influencing the design of a cathodic protection installation have been enumerated. The successful application of cathodic protection requires careful consideration of the design in order that adequate protection may be assured with the minimum overall cost.

Acknowledgment

The writer wishes to acknowledge with thanks the cooperation and helpful suggestions which he received from Arthur Friedman, Cleveland Heater Co., Clark Osterheld and D. F. Peck, of the Clark Water Heater Division of the McGraw Electric Co., Arthur Smith, Jr. and Harold A. Robinson of the Dow Chemical Co., and Frank P. Macdonald of the Electro Rust-Proofing Corporation.

References

1. Mears, R. B., and Brown, R. H., Causes of Corrosion Current, Industrial and Eng. Chem., **33**, 1001 (1941).
2. Brown, R. H., Fink, W. L., and Hunter, M. S., Measurement of Irreversible Potentials as a Metallurgical Research Tool, Metals Technology 7. T.P. No. 1234, Oct. 1940.
3. Brown, R. H., and Mears, R. B., Cathodic Protection, Trans. Electrochem. Soc., **81**, 455 (1942).
4. Briggs, R. H., Electrolytic Water Softening for Industrial Purposes, Sixth Annual Water Conference of Engineers Society of Western Pennsylvania, Pittsburgh, Pa., Oct. 22 and 23, 1945.
5. Streicher, Lee, Two Compartment Cell Softens Water Electrolytically, Civil Engineering, **16**, 312 (1946).
6. Smith, Arthur. Jr., The Dow Chemical Co., private communication.
7. Hoover, C. P., City Bulletin of Columbus, Annual Report, Division of Water, Columbus, Ohio, 1943.
8. Sudrabin, L. P., Cathodic Protection as a Corrosion Control Method Applied to Steel Surfaces Submerged in Water, Corrosion, 2, 175 (1946) June.
9. Sudrabin, L. P., Cathodic Protection of Steel Surfaces in Contact with Water, Water Works and Sewage, Reference and Data Issue, R-79, 1945.
10. Sudrabin, L. P., and Mears, R. B.,

Cathodic Protection of Steel Water Tanks using Aluminum Anodes, AIEE Technical Paper 47-30, Preprint Dec. 1946.
11. Elno Protector, Cleveland Heater Co., Cleveland, Ohio.
12. Robinson, H. A., The Dow Chemical Co., private communication.
13. Clark Ionodic System, Clark Water Heater Div., McGraw Electric Co., Chicago, Illinois.

Discussion

*By Leo J. Waldron**

Mr. Bialosky is to be congratulated on setting forth the principles involved in cathodic protection of domestic hot water tanks. A full understanding of the mechanism of the protection afforded by this proposed system of control is necessary if practical results are to be achieved.

The following remarks do not apply to the details covered in this paper but do have a direct relationship to the problem of corrosion of galvanized hot water tanks and range boilers.

The Federal Public Housing Authority have perhaps between one-quarter and one-half million domestic hot water tanks and range boilers in operation at various housing projects throughout the nation. All types of potable water are heated in these tanks.

The majority of these projects have been in operation for at least five years and corrosion of the tanks with their subsequent replacement is right now a very serious problem. At some locations, failures were reported after one year of service, with almost total replacement at the end of five years. Some projects estimate an annual replacement of as high as 25 percent of all tanks. Obviously, this results in an appreciable maintenance cost. A 10 percent average yearly replacement figure is conservative. Yet, this represents the purchase and installation of perhaps 50,000 tanks each year at a cost of over a million dollars. Consequently, any process, method of treatment, or improvements in materials and design which will increase the service performance of these tanks is worth investigating, provided it is economically sound. Such work is now included in the FPHA program of corrosion control in preventive maintenance.

The experiences with failures of hot water tanks being encountered by our organization are similar to those of millions of individual home owners and represent a challenge to all concerned for a product which will render better service.

* Corrosion Engineer, Federal Public Housing Authority, Washington, D. C.

Test of Nickel-Plated Pipe in Corrosive Distillate Well

*By B. B. Morton**

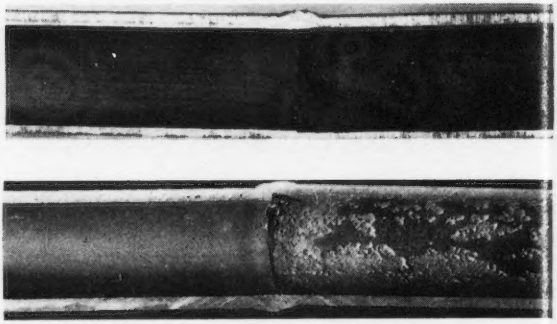


Figure 1—Top, appearance of pipe on inspection January 7, 1947, and bottom, on July 21, 1947. In both test illustrations, plated sections at left, carbon steel at right; flow left to right.

AS PART of the study of metals to resist the action of the corrosives found in some distillate wells, a 20-foot length of 2-inch, extra heavy line pipe was installed in the flow line of Grey-Cox No. 1 well, of the Cotton Valley Operators Association, Cotton Valley, Louisiana. The 2-inch pipe was nickel plated to a thickness of 0.006 inch on the inside by Bart Industries, of Belleville, New Jersey. The deposit is referred to as "Bart Electroplate" and is unique in being a controlled thickness of plating inside a 20-foot length of 2-inch pipe.

Table I

Test of Nickel Plated and Carbon Steel Tubing
Grey-Cox No. 1 Well
Cotton Valley, La.

Nickel plated tubing installed May 6, 1946.

Inspected July 12, 1946—Found in excellent condition.

Inspected January 21, 1947—Found in excellent condition.

Inspected July 7, 1947—Found in excellent condition.

Carbon steel pipe installed July 12, 1946.

Inspected January 21, 1947—Visibly corroded.

Inspected July 7, 1947—Corrosion has progressed.

Inspections have been made and samples taken from the nickel-plated pipe and the results are noted in Table I.

The tubing was inspected by taking sections sometimes at the inlet end and sometimes at the outlet, or as in the case of Figure 1, both ends simultaneously and sectioning the pipe for observation. An interesting feature of the nickel-plated pipe is the manner in which the nickel has protected deep scratches that existed at the time of plating.

The cooperation and interest of the management and engineers of the Cotton Valley Operators' Committee is thankfully acknowledged. These factors have made this test possible.

* Development and Research Division, The International Nickel Company, Inc., New York, N. Y.

Discussion of Paper, Chemical Reaction in Metal Protective Paints*

By W. Beck*

I HAVE READ Mr. Dunn's paper on "Chemical Reaction in Metal Protective Paints" with much interest and would like to make some additional remarks. Mr. Dunn has found a remarkable drop in the acid number of extracted, dried linseed paint films when these contain reactive lead oxide pigments. In my own investigations, I went a step further and measured the pH of the swelling water of the paint film. I was especially interested to determine the influence of the above-mentioned reaction in the various paint films on the pH of the swelling water. To make the swelling action as intense as possible, the films were powdered by grinding with rough quartz sand, and these powders, when added to a dilute sodium chloride solution, were shaken a number of months. From time to time pH measurements were made.

Results in Agreement

We found that the pH of the Pb_3O_4-linseed-oil film powder suspension was approximately between the pH of a suspension of the pure Pb_3O_4 pigment (average pH = 8.0) and the suspension of the linseed oil powder (average pH = 3.5). These results are in excellent agreement with Mr. Dunn's determinations of acid numbers in the extracts of pure and pigmented oil films.

Unreliable Opinion

This agreement extends even further. We extracted the so-called lead soaps from the pigmented film powder and succeeded in making very stable emulsions from these extracts in neutral water. The pH of these solutions agreed with the values obtained in the suspensions in the shaking experiments. The pH of the emulsion made from the acetone fraction was considerably more acid. These investigations show again how unreliable is the frequently repeated opinion that the protection against rusting by Pb_3O_4 oil films is a result of their ability to make the swelling water strongly alkaline.

At present we can only say with certainty that the swelling water in red lead pigmented linseed oil films is much less acid than in the pure oil film. Nor can it be said that the excellent protective action of these paints is a consequence of their com-

★ Dunn, E. J., CORROSION, 3, 374 (1947) Aug.
* Corrosion Research Department, Department of Metallurgical Engineering, Lehigh University, Bethlehem, Pa.

plete impenetrability to water. Mr. Dunn, for example, has shown that even highly efficient paint films still have hydrophilic properties.

Zahn's[1] potential measurements on iron electrodes protected by paint films, also made in the laboratories of the National Lead Company, would not have been possible if paint films were electrical insulators. For the best protection against rusting, the Pb_3O_4-oil layer must have a minimum permeability and its swelling water must have a minimum of acidity.

In our own studies we especially examined and improved the second condition. Because our original papers[2,3] are not generally available, I have briefly summarized the results at this time.

References

1. Zahn, H., Laboratory Evaluation of Corrosion-Resistant Pigments and Vehicles, Corrosion **3**, 233 (1947), May.
2. Beck, W., Chemisch Weekblad, **38**, 542 (1941) (Amsterdam).
3. Beck, W., Schweizer Archiv, **8**, 45 (1941).

STATEMENT OF THE OWNERSHIP, MANAGEMENT, CIRCULATION, ETC., REQUIRED BY THE ACT OF CONGRESS OF AUGUST 24, 1912, AS AMENDED BY THE ACTS OF MARCH 3, 1933, AND JULY 2, 1946, Of Corrosion, published monthly at Houston, Texas, for October 1, 1947.

State of Texas, County of Harris, ss:

Before me, a Notary Public in and for the State and County aforesaid, personally appeared A. B. Campbell, who, having been duly sworn according to law, deposes and says that he is the Executive Secretary of Corrosion and that the following is, to the best of his knowledge and belief, a true statement of the ownership, management (and if a daily, weekly, semiweekly or triweekly newspaper, the circulation), etc., of the aforesaid publication for the date shown in the above caption, required by the Act of August 24, 1912, as amended by the Acts of March 3, 1933, and July 2, 1946, Section 537, Postal Laws and Regulation, printed on the reverse of this form, to wit:

1. That the names and addresses of the publisher, editor, managing editor, and business managers are: Publisher, National Association of Corrosion Engineers, 711 Main St., Houston, Texas; Editor, Dr. Ivy M. Parker, Box 266, Bremen, Ga.; Managing Editor, W. M. Wernett, 905 Southern Standard Bldg., 711 Main St., Houston, Texas; Executive Secretary, A. B. Campbell, 711 Main St., Houston Texas.

2. That the owner is: (If owned by a corporation, its name and address must be stated and also immediately thereunder the names and addresses of stockholders owning or holding 1 percent or more of total amount of stock.)

The National Association of Corrosion Engineers, Houston, Texas. A non-profit organization, therefore no stock issued.

3. That the known bondholders, mortgagees, and other security holders owning or holding 1 percent or more of total amount of bonds, mortgages, or other securities are: None.

4. That the two paragraphs next above, giving the names of the owners, stockholders and security holders, if any, contain not only the list of stockholders and security holders as they appear upon the books of the company but also, in cases where the stockholder or security holder appears upon the books of the company as trustee or in any other fiduciary relation, the name of the person or corporation for whom such trustee is acting is given; also that the said two paragraphs contain statements embracing affiant's full knowledge and belief as to the circumstances and conditions under which stockholders and security holders who do not appear upon the books of the company as trustees, hold stock and security in a capacity other than that of a bona fide owner; and this affiant has no reason to believe that any other person, association or corporation has any interest direct or indirect in the said stock, bonds, or other securities than as so stated by him.

5. That the average number of copies of each issue of this publication sold or distributed, through the mails or otherwise, to paid subscribers during the twelve months preceding the date shown above is (This information is required from daily, weekly, semiweekly, and triweekly newspapers only.)

A. B. CAMPBELL, Executive Secretary.

Sworn to and subscribed before me this 11th day of September, 1947.

ELEANOR WILLIAMS.

(Seal) Notary Public in and for Harris County, Texas.
(My commission expires June 1, 1949.)

A Message from Your Officers

This Month's Contributor

R. B. MEARS, Chairman Technical Practices Committee

MR. A. B. CAMPBELL, our Executive Secretary, in his communication in the September, 1947, issue of CORROSION has emphasized the importance of technical committees as a means of correlating corrosion information on making it available to interested individuals or organizations. I heartily agree with Mr. Campbell's contention and feel that the potential value of active technical committees cannot be stressed too much.

According to our Association's plan of organization, the various technical committees are in a sense sub-committees of the Technical Practices Committee. The Technical Practices Committee is held responsible for implementing the desires of the members in organizing specific technical committees and delineating the spheres of responsibility for each.

At present, nine technical committees have been formed. These are as follows, listed approximately according to their order of formation:

1. Condensate Well Corrosion—Chairman: Mr. W. F. Rogers, Gulf Oil Corporation, P. O. Box 2100, Houston 1, Texas.
2. Galvanic Anodes for Cathodic Protection—Chairman: Mr. M. C. Miller, Ebasco Services, Inc., 2 Rector Street, New York 6, N. Y.
3. Anodes for Use with Impressed Currents—Chairman: Mr. D. H. Bond, Texas Pipe Line Company, P. O. Box 2332, Houston 1, Texas.
4. Minimum Current Requirements for Cathodic Protection—Chairman: Mr. A. V. Smith, Consultant, 1617 Pennsylvania Blvd., Philadelphia 3, Pennsylvania.
5. Corrosion Problems Involved in Processing and Handling Chemicals—Chairman: Mr. Mars G. Fontana, The Ohio State University, Columbus 10, Ohio.
6. Protective Coatings—Chairman: Mr. Tom L. Holcombe, Dearborn Chemical Company, 324 Ardis Bldg., Shreveport, Louisiana.
7. Materials for Use at High Temperatures—Chairman: Mr. M. A. Scheil, A. O. Smith Corporation, Milwaukee 1, Wisconsin.
8. Corrosion Problems Involved in Handling Inland Waters—Chairman: Mr. V. V. Kendall, National Tube Company, Box 266, Pittsburgh, Pennsylvania.

It is also planned to initiate a committee on Corrosion Inhibitors.

Members interested in the work of any of the above committees should communicate with the appropriate chairman. The Technical Practices Committee will also be glad to consider suggestions as to the desirability of initiating other committee activity.

NACE News

Cleveland Corrosion Symposium Attracts 300

The estimated annual cost of corrosion to the world is $10 billion, and this would be multiplied many fold if it were not for protective coatings, estimated at one-half billion dollars for raw materials, with application cost several times the materials cost, K. G. Compton, Finish and Corrosion Engineer of the Bell Telephone Laboratories, told 300 chemists and engineers at the Symposium on Modern Metal Protection, held in Cleveland September 27. Mr. Compton, whose paper was titled, "Selection of Protective Coatings for Metal Protection," was one of seven persons to present papers at the meeting. Other speakers were H. O. Teeple, Corrosion Engineering Section, Development and Research Laboratories, The International Nickel Co., Inc., who presented the paper, "Some Notes on the Corrosion Behavior of High Nickel Alloys and Stainless Steels;" H. L. Maxwell, E. I. du Pont de Nemours & Co., who read the paper, "Corrosion Resistant Chemical Equipment of Stainless Steel," which had been drawn up in collaboration with W. R. Myers, also of du Pont; R. B. Long, Haynes Stellite Company, who read the paper, "Corrosion Resistance of Hastelloy Alloys and Application in Processing Equipment." J. B. Martin, Hercules Powder Company, who presented the paper, "Synthetic Rubber Derivatives as Corrosion Resistant Coatings;" W. N. Harrison, National Bureau of Standards, who presented a paper titled, "Protective Coatings for High Temperature Applications," and George W. Seagren, Mellon Institute of Industrial Research, who read the paper, "Organic Coatings for Corrosion Protection."

Interest in the meeting was evidenced by the large attendance, which included visitors from Chicago, New York, Birmingham, Baton Rouge and Milwaukee as well as groups from various parts of Pennsylvania and Southern Ohio.

The meeting was jointly sponsored by local sections of the American Chemical Society, American Institute of Chemical Engineers and Electrochemical Society. The Cleveland Section of the National Association of Corrosion Engineers was formed too late to sponsor the meeting, but members gave their full support in making the session a complete success.

FRENCH ENGINEERS HEAR TECHNICAL PAPERS PREPARED BY AMERICAN CORROSION EXPERTS

Among the many papers read during the International Congress on Corrosion, held October 7 at Paris, France, and sponsored by The Societe Francaise de Metallurgie Commission Technique Des Etats de Surface, two which drew considerable comment were, "Some Methods for Studying the Behavior of Alloys in Sea Water at High Velocities," which was jointly prepared by F. L. LaQue, in charge of the Corrosion Section of The International Nickel Co., Inc., and Vice President of the National Association of Corrosion Engineers; and W. C. Stewart, Chief Metallurgist, U. S. Naval Engineering Experimental Station; and "Precious Metals in the Chemical Industry," by Edmund C. Wise, also of the International Nickel staff. Both papers were read by Maurice Ballay, director of research of the Center d'Information du Nickel, Paris.

Behavior of Alloys in Salt Water

Described in the paper prepared by Messrs. LaQue and Stewart were three types of apparatus with which the authors have studied the behavior of various alloys in contact with rapidly moving salt water. These devices have made it possible to record various factors which influence corrosion.

Tests in brackish waters do not serve adequately to disclose the behavior of all compositions in full strength sea water, nor does synthetic sea water serve adequately to disclose the behavior of alloys in contact with natural sea water at high velocity. Results of experiments showed that attack by sea water generally increases in severity with temperature and velocity.

Tests also revealed that air bubbles, which are harmful to some alloys, have little effect and may even be beneficial to other alloys. The data cited served to further establish the advantage of the addition of iron to the 70/30 cupro-nickel alloy in achieving maximum resistance to destructive effects of velocity, air bubbles, temperature and salinity.

Use of Precious Metals

Mr. Wise's paper dealt primarily with the industrial uses of the precious metals. A large amount of new data on the corrosion resistance of these metals were summarized, and the industrial applications and properties responsible for their use were discussed. It was pointed out that

Nominate Officers

• A business meeting of the Western Regional Division of the National Association of Corrosion Engineers was held October 1 in Los Angeles for the purpose of nominating Regional officers for 1948. Nominations were as follows:

Chairman—Irwin C. Dietze, Department of Water and Power, City of Los Angeles.

Vice Chairman—Kenyon Wells, Long Beach Water Department.

Secretary-Treasurer—C. A. Goldkamp, San Diego Gas & Electric Corp.

Ballots have been forwarded to all members in the Division, and results will be tabulated and made known at a meeting tentatively scheduled for November 5.

certain precious metals have the ability to withstand environments that would destroy other materials, as illustrated by the use of platinum in handling glass in the fiber glass industry, made possible by the unique resistance of platinum to molten glass.

The author also indicated that the economics of the use of platinum is best evidenced from the selection of materials on the bases of performance life and product quality rather than initial cost. In their uses as catalysts, the author showed that precious metals have higher conversion efficiency and the ability to function at lower temperatures and pressures. Use in ammonia oxidation and the synthesis of complex organics was cited. Outside the chemical industry, the good behavior of precious metals as electrical contacts was described as being due in general to resistance to oxidation. An illustration of this point is the use of palladium contacts in telephone relays in all voice circuits, which contributes to the low noise level and reliability of telephone circuits in the U. S.

GENERAL INTEREST

A joint meeting of the Chicago Section of the North Central Regional Division of the National Association of Corrosion Engineers, and the Electrochemical Society was held in Chicago October 3. R. B. Mears, Manager of the Research Laboratories, Carnegie-Illinois Steel Corp., and Chairman of the Technical Practices Committee and member of the NACE Board of Directors, was the principal speaker. Mr. Mears presented a paper entitled, "Causes of Localized Attack."

Notice

• Effective January 1, 1948, subscription to the National Association of Corrosion Engineers' journal, CORROSION, will be $7.50 per year, with a $3.50 per year rate extended to educational and public libraries. The present method of allocating $3.00 of Members' $7.50 dues for a subscription to CORROSION will continue in force.

W. H. Keller, Johns-Manville Sales Corp., St. Louis, has accepted appointment as chairman of the Committee on Local Arrangements for the NACE 1948 St. Louis Conference and Exhibition, according to F. L. Goldsby, chairman of the Conference Committee for the April 5-8 corrosion show. Working with Mr. Keller in St. Louis will be **F. E. Dolson,** St. Louis County Water Co., chairman of the Registration and Information Committee; **W. E. Gross,** Tret-O-Lite Company, chairman of the Entertainment Committee; **Clarence E. Mange,** C. E. Mange Development Laboratory, in charge of local printing, and **Miss Mary Nolan,** secretary to E. Morrill, Sohio Pipe Line Co., chairman of the Ladies' Committee.

T. F. P. Kelly, of James E. Mavor Company, Houston, Texas, has been named Chairman of the Welcoming Committee for the 1948 NACE Conference and Exhibition.

Fred L. Goldsby, recently appointed manager of the Foreign Erection Department, Chicago Bridge & Iron Works, a Director of the National Association of Corrosion Engineers, and Chairman of the 1948 NACE Conference and Exhibition, was one of the principal speakers on the opening day of the three-day Petroleum Mechanical Engineering conference of the American Society of Mechanical Engineers, held in Houston, Texas, October 6 through 8. Mr. Goldsby presented the paper entitled, "Accessories for Good Operation of Pressure Storage Vessels." While in Houston, Mr. Goldsby discussed plans for the NACE Corrosion Show with President G. R. Olson, Treasurer O. C. Mudd, Executive Secretary A. B. Campbell, T. F. P. Kelly, Gene Rolfs, Jack Harris, Donald Bond, and Russell Brannon.

The Sam Tour Award has been established by the American Society for Testing Materials, Philadelphia, Pa. The award, $1500, is sponsored by Sam Tour, president of Sam Tour, Inc., New York, and is set up as an incentive to undertake research in corrosion testing, and to stimulate preparation of technical papers in this field.

An accelerated weathering machine is being used in the Bessemer Avenue plant of Arco Co., Cleveland, Ohio, to test finishes the company supplies to customers. The accelerated test method employed is said to achieve in three weeks results equivalent to a one-year outdoor exposure under subtropical conditions. The machine subjects specimens to strong electric "sunshine," and "periodic "rain."

PERSONALS

John H. Thomas has succeeded George E. Gregory as vice president and purchasing director of Owens-Corning Fiberglas Corporation, and Ben S. Wright has become general purchasing agent of the firm. These changes, which were effective October 1, were announced by Harold Boeschenestein, Fiberglas president, following word of Mr. Gregory's resignation from Owens-Corning to become president of the Morton-Gregory Company, Inc., a new organization being formed to manufacture and distribute industrial and consumer products calling for large-scale use of Fiberglas yarn.

Stuart O. Fielder has resigned as manager of the South Chicago Branch of the Bjorksten Research Laboratories, Chicago, to accept the

***THE NEWS SECTION** was primarily incorporated in Corrosion to provide a record of the current activities of members of the Association, and to convey information of interest and value to members. All members are invited (in fact urged) to send releases, or letters, informing the editors of changes in positions, promotions, achievements, or other news items. All material should be forwarded to the Editor of CORROSION, 905 Southern Standard Bldg., 711 Main Street, Houston 2, Texas.*

position as manager of research for the Industrial Rayon Corporation, Cleveland, Ohio. Mr. Fielder, who will remain a director of the Bjorksten laboratories, joined the Bjorksten organization in 1945, and the same year was appointed manager of the South Chicago branch. In 1946, he was made a vice president. Previously, he was associated with the Burgess Laboratories, Madison, Wis., and was with E. I. du Pont De Nemours & Co., for 15 years.

W. A. Pennington, chief chemist and metallurgist of Carrier Corporation, was awarded the Henry Marion Howe Medal by the American Society of Metals for preparing the "outstanding paper" "A Mechanism of the Surface Decarburization of Steel," presented in the Transactions of the Society. The award was presented during the ASM meeting October 23 in Chicago.

Charles R. Hook, president of the American Rolling Mill Co., also was honored by ASM, being awarded the Medal for the Advancement of Research. Two other awards were presented during the meeting: **C. W. Mathewson,** professor of metallurgy, Yale University, received the ASM Gold Medal, and **F. P. Zimmerli,** chief engineer of Barnes-Gibson-Raymond, received the Sauveur Achievement Award.

H. E. Johnson has been appointed Chicago district manager of the Alloy Steel Products Company, Linden, N. J., manufacturers of corrosion-resistant valves and fittings. Mr. Johnson's headquarters will be in the new sales office the company has established at 332 S. Michigan Ave.

Lance H. Cooper, London, England, a member of the staff of The Mond Nickel Company for 20 years, and one of its Delegate Directors since 1945, has been elected an Assistant Secretary and Assistant Treasurer of The International Nickel Company of Canada, Limited, according to John F. Thompson, executive vice president of Internatoinal Nickel of Canada.

Harmon Leis has resigned as president and director of the Alcoa Steamship Co., and as director of several subsidiary companies of the Aluminum Company of America, Pittsburgh, to take an active part in the management of the Warren McArthur Corporation, Litchfield, Conn. He was succeeded in the presidency of Alcoa Steamship Co., by William C. White, vice president of that company, who has been associated with Alcoa and its subsidiaries since 1928.

R. G. McElwee, manager, Foundry Alloy Division, Vanadium Corporation of America, New York, has been named chairman of the Gray Iron Division of the American Foundrymen's Association.

W. B. Holton, Jr., president of Walworth Co., New York, has been presented the President's Certificate of Merit for "outstanding contributions" to the Navy's shipbuilding and repair programs during World War II.

NEW PRODUCTS, MATERIALS AND SERVICES

Bee Chemical Company, Chicago, has been licensed to manufacture and distribute "Logoquant," a new material for treatment of polystrene plastics developed by the Bjorksten Research Laboratories, Chicago, for Nash-Kelvinator Corporation. The new treatment, making possible use of low-cost polystrene for various industrial applications, has been developed for production line application, either by spraying or dipping. It does not require special equipment, nor curing at high temperatures. The treatment can be completed in 15 minutes. The Logoquant treatment depends on actual fusion between polystrene and resistant materials. Treated polystrene is indistinguishable from untreated polystrene it is reported, even when transparent polystrene is used. It is claimed that the treated surface cannot be peeled off. The treatment imparts to polystrene a mar resistance 18 percent higher than in an untreated state, seven percent higher than that of a good spar varnish, and in the same order of magnitude as more expensive plastics, according to measurements determined by method D 673-44 ASTM standard. This test method consists of dropping carborundum grits from a height of 25 inches, and measuring the dulling effect on the sharp grit on the plastic by photoelectric means. The treated polystrene can be polished to clearness more easily than untreated polystrene, and the treated material is considerably less electrostatic. Polystrene treated with "Logoquant" is said to be resistant to wiping and brushing with gasoline, mineral oils, carbon tetrachloride and toulene. The new material will probably find wide use in the automotive industry.

Designed for cleaning aluminum, a new cleaner is being manufactured by the Optimus Detergents Co., 152 Water St., Matawan, N. J. The cleaner, to be known as No. 101A, is a blend of medium duty alkaline cleaner, including water softening materials and inhibitors to prevent attack on the metal. Effective for cleaning dirt, grease and oil, it will also clean die castings, brass, bronze, pewter, etc., when used as a soak cleaner. Containing a wetting agent, the new product may be used in low concentrations with temperatures ranging between 140 and 180° F.

A Corrosion resisitant pressure gage to be used in handling non-aerated acetic acid, alcohol, sodium acid sulfate, oxalic acid, carbon tetrachloride, tannic acid, sulfuric acid and other acids is being manufactured by the James P. Marsch Corporation, 2073 Southport Avenue, Chicago. Made in several case styles and dial sizes, the gage has a lathe-turned beryllium copper bourbon tube, copper locktite cones and tip and socket made from brass bar stock. The movement has bronze bushings.

Stainless steel powder base paint, using a spar varnish or lacquer vehicle, is now available commercially, according to John D. Hale, president of Charles Hardy, Inc., New York. A number of leading paint manufacturers are presently engaged in testing physical qualities of stainless steel powder base paint, and results achieved thus far should further expand availability of stainless base paint to distributors. The material is supplied in a paste form, which, when mixed with any commercial vehicle, will render a surface highly resistant to such corrosive agents as nitric, phosphoric or sulfuric acid fumes or other strong chemicals.

A welding rod designed for use at low temperature on zinc-base castings, has been developed by the All-State Welding Alloys Co., Inc., 96 West Post Road, White Plains, N. Y. Available in a 3/32-inch round form, it is said to be easily applied at a working temperature of 400° F., and a shear strength of 25,000 psi.

NEW BOOKS AND LITERATURE

A 16-page booklet on the materials required for the metal-arc, oxy-acetylene and submerged melt welding of nickel and the high nickel alloys has been published by The International Nickel Co., Inc., 67 Wall Street, New York. The booklet also lists such general information as the type of welding rods to use, recommended amperage for electric arc-welding, and the proper flux to select for gas welding and brazing. Information also is included on technical booklets on the subject of welding of the high nickel alloys and sources of supply for electrodes and gas welding wire. It is being distributed without charge.

Duriron Company, Dayton, Ohio, has published an 8-page illustrated catalog which gives a brief description of all types of corrosion-resistant equipment manufactured by the company. Thirty-six products fabricated from corrosion-resistant alloys are covered and data given on each. Products include pumps, pipe, valves, fans, heat exchangers, steam jets, ejectors, tank outlets and mixing nozzles.

The "Reflectogage" is described in literature available from Sperry Products, Inc., 15th Street and Willow Avenue, Hoboken, N. J. The Reflectogage, an instrument utilizing supersonics for thickness measurement and flaw detection, supplements the Supersonic Reflectoscope and the Thruray. The new instrument makes it possible to measure thickness of metals and other materials where access from only one side is available. Maximum error in measurement, according to the pamphlet, is less than two percent of the total thickness. Thickness of tubing and flat parts between .005 and 0.3 inch can be read from the face of the oscilloscope screen. Indirect readings up to four inches are accomplished by calculation.

Corrosion Abstracts

ATMOSPHERIC CORROSION

Corrosion of Steels in Marine Atmosphere and in Sea-Water. C. P. LARRABEE, Trans. Electrochem. Soc., **37,** 123-40 (1945).

The results of exposure tests at several stations are described and discussed in conjunction with data from other published work. In marine atmospheres the low-alloy steels are superior to the plain steels, as in industrial atmospheres. The degrees of superiority can be found only by tests which closely resemble service conditions. Only the very highly alloyed stainless steels remain untarnished, but the lower grades are only slightly rusted. Zinc-coated steel is quite satisfactory under many conditions. In seawater the rate of penetration of mild steel varies between 0.002 and 0.0077 in. per year while the average rate for plain and low-alloy steels is 0.004 in. per year. Normally the use of low-alloy steels can be justified only by tests under service conditions. The corrosion of steels exposed between low and high tides is very variable. Austentitic stainless steels are liable to pitting unless they are highly alloyed or contain an addition of 2-3% of molybdenum.—CEC.

BOILER CORROSION

Boiler Scale Removal by Chemical Cleaning. B. J. COTEY. Power Plant Eng., **50,** 8, 75-77 (1946) Aug.

Removal of boiler scale is difficult because although acid will remove the scale it also reacts with the metal. Therefore, it is necessary to use an inhibitor, the best type depending on the concentration and type of acid and the process employed. Carbonates and phosphates are easily removed, silicates and oxides more difficult, and pure silica or pure sulphate almost impossible. Oil requires special treatment. There are two general methods of cleaning boilers, (1) fill-and-soak, (2) pump circulation. Cleaning procedure: fill the unit with recommended solvent, allow to soak or circulate until all scale disintegrates, drain, fill with water, drain, fill with boiler neutralizing compound, boil and then drain. Filling of boiler and heating of solution are described in detail. Photo. and diagr.—INCO.

How to Control Marine Growths in Circulating Water Systems. J. G. DOBSON. Power Plant Eng., **50,** 8, 70-75 (1946) Aug; Trans. ASME **68,** 3, 247-265 (1946) Apr.

One way to prevent or control fouling is by chlorination. If complete prevention is required then continuous chlorination during fouling season must be employed. However, if only control is required, then intermittent chlorination may be used. The time interval for intermittent chlorination once established must be maintained rigidly as it is necessary to keep killing the organisms. Action of chlorine

in killing organisms, starting control operation, application of chlorine to large water flows, seasonal factor, determination of the rate of fouling, and ways to design for fouling conditions are given. Chlorine will not affect surrounding waters.—INCO.

CHEMICAL CORROSION

Reactions with Steel Compounds Containing Chemical Groups Used in Lubricant Additives. ALLEN S. POWELL. National Advisory Committee for Aeronautics, Washington. (Technical Note No. 1207.)

Reactions between steel of a type used in aircraft-engine cylinder barrels and compounds containing reactive groups commonly found in lubricant additives were investigated. Products formed by reaction at temperatures from 400 to 650° F. were analyzed by reflection electron diffraction.—BLR.

Chlorination in the Food Plant. Part II. J. J. HARRIS. Canner, **103,** 14-15 (1946) Aug.; Corr. & Mat. Prot., **4,** 2, 25 (1947) Mar.-Apr.

Includes discussion of corrosion problems. Where cooling water contains corrosive compounds such as high sulphates and chlorides, addition of chlorine will increase greatly tendency of containers to corrode, particularly if excessive amounts are used. This can be counteracted by addition of a corrosion inhibitor, such as sodium chromate. Additions of chlorine far in excess of that required for bacteriological control of the average cooling waters does not result in corrosion. However, chlorine in boiler water make up may result in corrosion. With proper control of chlorine no abnormal corrosion has been noted in continuous coolers.—INCO.

Mechanical Filtration with Metal Filter-Cloths. R. F. BLACK, Int. Sugar J., **48,** 207-208 (1946) Aug.; Corr. & Mat. Prot., **4,** 1, 25 (1947) Jan.-Feb.

Corrosion of metal filter leaves in cane-sugar refineries is discussed. Various materials have been tried, but none has been as satisfactory in all products as monel metal. A molybdenum stainless steel which showed no general corrosion, developed corrosion pits in low-purity syrups. Rapid electrolytic corrosion of Monel-covered leaves occurred in a high-purity liquor because of sweating. Thorough washing of the filter and leaving it wide open for circulation of air to dry it during shut-down periods stopped this electrolytic corrosion and caused no undue rusting of the cast-iron filter body.—INCO.

Nitric Acid from Ammonia. F. E. WARNER. Paper before Inst. of Chem. Engr., Chem. Trade J. & Chem. Engr., **119,** 698, 700-701 (1946) Dec. 13.; Corr. & Mat. Prot., **4,** 2, (1947) Mar.-Apr.

Deals with manufacture by pressure oxidation of ammonia. Use of a mild-steel wast-heat boiler solved many problems of heat and corrosion resistance. The tubes were maintained at a temperature low enough to avoid oxidation scaling completely but well above the dew-point at which condensation of acid takes place. Beyond the boiler, stainless steel is used for further gas cooling, condensation, and absorption. Corrosion of preheater tubes was overcome by installing the preheater on its side with a good slope so that condensate could be

drained away. Siliconiron parts are used in the concentration of nitric acid by means of concentrated sulphuric acid. Aluminum and stainless steel are used for transfer and storage of nitric acid. No completely satisfactory pump for handling concentrated nitric acid was found.
—INCO.

Solution of Copper in Nitric Acid. A. I. KRASIL'SHCHIKOV and I. V. DEIOVA. Moscow State Inst. Nitrog. Ind. J., Gen. Chem. (USSR) **16,** 537-542 (1946); Chem. Abs., **41,** 5, 1145 (1947) Mar. 10.

The process of solution of copper in nitcric acid was studied. The rate of solution rapidly rises with increased temperature and acid concentration (results given graphically). It is suggested that either copper ions or nitrons acid may act as autocatalysts in the solution process. It is also proposed that, in view of the very high temperature coefficient, the over-all solution is a function of minute electrochemical reactions on the surface of copper involving local potential differences which account for the high order of temperature dependence.—INCO.

Nitric Acid Production. F. E. WARNER. Ind. Chem. **23,** 17-25 (1947) Jan. Paper before Inst. of Chem. Engrs., Dec. 3.

Ammonia-air mixtures are burnt by passage through a pad consisting of 18 to 24 ten percent. Rhodium-Platinum gauges, clamped between a nickel ring and a 25 percent chromium- 20 percent nickel support, with nichrome crossbars. In the conversion section of the plant, where temperatures are up to 900° C. and working pressures up to 100 psi, creep is prevented by using stainless-steel of adequate section. A 25-20 chromium-nickel-iron alloy is used for shielding the boiler top tube-plate. The converter head is of stainless-steel, polished internally, and unlagged, to allow the working temperature to be kept down by radiation.—INCO.

Organic Chloride Resistance. Oil & Gas J., **45,** 51, 166 (1947) Apr. 26.

Plant corrosion tests are reported by Lukens Steel Co. on the resistance of Monel, nickel, Inconel, Hastelloy A and carbon, Nickel-Resist (type: 5 and 1) and 1 nickel cast iron to the action of chlorine, hydrochloric acid, and acetylene tetrachloride. Conditions of test are described.—INO.

COATINGS

Investigation of Methods of Determining Weight or Average Thickness of Tin or Tin-Coated Copper and Brass. H. R. HANNA, ASTM Bull. **143,** 35-37 (1946) Dec.

Author considers 15 methods, in some cases carrying out experimental work. He recommends stripping in a boiling caustic soda solution containing suspended bismuth hydroxide, from which bismuth can be recovered after use. Methods using solution of caustic soda and potassium iodate or solution of trichloroacetic acid are given as alternatives.—BNF.

Corrosion Tests on Plated Electron. H. GROEBER. Headquarters Air Material Command, Wright Field, Dayton, Ohio, (1947) Feb.

Refers to a German alloy. AZ-

885 Metal sheets plated with AM-503 showed mechanical properties which were practically the same as for the unplated material. The new material was better than AM-503 with respect to corrosion without mechanical loads.—BLR.

Cadmium Plate and Passivated Cadmium-Plate Coatings. E. E. MALLS. (Comment by F. TAYLOR). Metallurgia, **34**, 203, 295-297 (1946) Sept.; Ibid. 204, 28-31 (1946) Nov.; Ibid. 205, 63 (1946) Dec.

Original article reports comparative tests of cadmium-plated mild steel, brass and copper given a chromate passivation dip and a standard chromate passivation treatment. Tables give full results, including salt spray data, which indicate that the simple treatment advocated adds serviceability to coating out of all proportion to the small effort and coats. Both the original article and comments which follow in next installment by F. Taylor discuss the use of cadmium vs. zinc, and the general usefulness of cadmium-plating. Mr. Taylor asks for comparative data from zinc-plated specimens, which were secured and are shown in the Dec. installment. He also advocates the use of a nickel flash (or tin) between the parent metal and cadmium plating. Especial usefulness of cadmium-plating in the radio industry and for soldering is mentioned. Tests were humidity, as well as salt spray.—INCO.

The Value of Tin on a Can. W. R. LEWIS. Tin and Its Uses, **16**, 5, 7 (1945); J. Inst. of Metals and Metall. **14**, 56 (1947) Feb.

Describes British and American studies on the use of laquered bonderized blackplate and thinly-coated electrolytic tinplate as substitutes for hot-dipped tinplate. Both substitutes have serious practical limitations as regards corrosion-resistance, and a return to hot-dipped tinplate for processed food cans is indicated.—INCO.

Electro-Tinplate, Part II.—The Influence of Coating Thickness on the Porosity and Resistance to Corrosion of Electro-Tinplate. R. KERR R. M. ANGLES and K. W. CAULFIELD. J. Soc. of Chem. Ind., **66**, 1, 5-7 (1947) Jan.

A study of the effect of variation in coating thickness on the quality of electro-tinplate deposited from the stannous sulphate and sodium stannate baths. All of the tests reveal a deterioration in the quality of the deposits as the thickness diminshes. As estimated by the thiocyanate, hot-water porosity, humidity and salt spray tests minimum thickness was found to be 12 oz. per basic box.—INCO.

Electro-Tinplate. Part III.—The Influence of Pickling Conditions on the Porosity and Corrosion Resistance of Electro-Tinplate. K. W. CAULFIELD, R. KERR and R. M. ANGLES. J. Soc. of Chem. Ind., **66**, 1, 7-11 (1947) Jan.

The quality of electro-tinned coatings from the alkaline and acid baths, on steel, was determined by thiocyanate test, humidity chamber test and visual appearance after the following pre-plating treatments: pickling in various acid baths, anodic etching in sulphuric acid, and anodic pickling in inhib-

ited sulphuric acid. Coatings of equally high quality can be deposited from either bath, but the deposit from the alkaline bath is less sensitive to pickling procedure than is that from the acid bath. The best pre-treatment for alkaline bath deposits is pickling in inhibited sulphuric acid, and for acid bath deposits is anodic etching in sulphuric acid. Pickling in hydrochloric acid leads to coatings of slightly lower quality, but is equally effective with alkaline and acid bath deposits and there is no deterioration on prolonging the pickling time up to five minutes.—INCO.

Protection of Iron and Steel by Metallic Coatings: Results of Five Years' Exposure Tests. J. C. Hudson and T. A. Banfield. Iron & Steel Inst. Adv. Copy, 36 pp. (1946) Dec.

Paper submitted by the Protective Coatings (Corrosion) Sub-Committee of the Iron and Steel Institute and the British Iron and Steel Research Association. These five-year atmospheric and sea-water exposure tests were carried out on mild steel plates (0.20 percent carbon, 0.60 percent manganese, 0.5 percent silicon) protected by a wide range of metallic coatings. Industrial, rural, sea-shore, tropical and semi-tropical locations were used for the atmospheric tests and total immersion in the sea (England and Wales) for the sea-water tests. The coating metals were: aluminum (calorized, hot-dipped, hot-dipped and heat-treated, sprayed); cadmium (electrodeposited, sprayed); 82/18 cadmium-zinc alloy (sprayed); zinc (sherardized, electrodeposited, hot-dipped, sprayed); lead electrodeposited, hot-dipped, sprayed); 88/12 lead-tin (hot-dipped, sprayed); tin (electrodeposited, hot-dipped, sprayed). Some specimens were in addition given two coats of red-oxide paint. In some cases the coating thickness was varied and protective supplementary rinses applied; all three systems of metal spraying (wire, molten-metal and powder pistols) were generally used. Full experimental details and discussions of the results are given.
—BNF.

Galvanized Steel Wire. Fred M. Crapo. Wire & Wire Prod., **22,** 31-42 (1947) Jan.

Reviews the development and present status of wire galvanizing processes. 81 ref.—BLR.

Production Processes: Their Influence on Design. Part XIX.—Metallizing. R. W. Bolz. Machine Design, **19,** 105-110 (1947) Jan.

Metallizing is discussed with particular attention paid to its use for purposes other than corrosion resistance; methods of surface preparation described include the electric bonding method consisting of stroking a number of nickel electrodes over the surface leaving it coated with a frothy layer of nickel about 0.006 in. thick.—BNF.

Steel Pipe Electroplated Inside for Corrosion Resistance. S. G. Bart, Corr. & Mat. Prot., **3,** 8-10 (1946) Oct.-Dec.

By a predetermined thickness of nickel or other corrosion-resistant metal can be electroplated on inside of tubes, fittings, etc. Coating is smooth and adherent and the tubes

can be subsequently drawn down, bent or welded. Few details are given of the process, which was used on a large scale during the war.—BNF.

Weathering Effects on Magnesium Coatings. L. R. WILLIAMS and G. W. SEARS. Light Metal Age (U.S.A.) **5,** 4, 10-11, 22, (1947) Apr.

Studies have been made of the effectiveness of surface coatings in preventing the corrosion of magnesium and its alloys under climatic conditions in western Nevada. The sheet magnesium and surface coatings used were of commercial grade, furnished by five different manufacturers. The approximate composition of the magnesium alloy was: aluminum 3.5, magnese 0.1, zinc 1.3, magnesium 95.1 percent. The test plates were cleaned and subjected to a chemical treatment, "chrome pickle," recommended by Dow Chemical Co. Protective coatings were applied to both sides of the "chrome pickled" plates and placed on a weather rack at 45° south in March, 1945. After fourteen months weathering, the plates were removed and examined under a microscope and any evidence of surface failure such as checking, pitting, chalking and fading were noted. The following conclusions are drawn: 1) high grade protective coatings for magnesium have been commercially manufactured; 2) the problem of adherence of the prime coat to the magnesium surface seems well solved. In all, nine different prime coats were tested either alone or under top coats of various kinds and in only one or two cases was there any evidence of failure to adhere to the magnesium; 3) the effectiveness of a top coat varies greatly with the nature of the prime coat used under it. This appears to be due to the degree of compatability of the two coats rather than to the particular quality of either. To supplement the evidence of the effectiveness of protective coatings, the test plates were subjected to salt water treatment for six weeks. At the end of the period, the plates were examined. Any corrosion of the magnesium surface was taken as an indication of a break in the protective coating surface as a result of weathering since blank tests had shown that none of the unweathered protective coatings were affected by the salt water treatment.

—ALL.

Aviation. Russian Technical Research News, **1,** (1946); Metals Rev. **20,** 1, 20 (1947) Jan.

Corrosion of valve heads is one of the major problems involved in increasing degree of supercharging and compression in airplane motors. Coating entire valve head with a special alloy is recommended. The alloy contains 30 percent chromium, 65 percent nickel, small percentage of silicon, aluminum and iron, and also minor amounts of calcium, cerium, and thorium.—INCO.

Painting with Molten Metal. Marine Eng. Shipping Rev., **52,** 2, 138 (1947) Feb.

Frames and panels of Westinghouse radio-communication equipments are protected by molten-metal spray, in which the steel was first shot-blasted and then painted with a film of molten zinc. Method is applied to the protection of shunt capacitors for pole mounting where

ordinary paints are inadequate because the handling during installation often scores the surface, paving the way for early corrosion. It is applied to transmission-line protector tubes and may be extended to other communication equipments, train-radio sets, and broadcasting equipments located in certain localities. This protection is useful for other apparatus that must be subjected to corrosive atmosphere such as salt air.—INCO.

Zinc Coatings. Sessions at Corrosion Forum. Corr. & Mat. Prot., **3,** 7, 8-14 (1946) Aug.-Sept.

Various zinc coating processes are presented with their advantages. The series of articles include: Zinc Spraying, J. Howat; Electroplating of Zinc, I. Schmidt; Calorizing, B. J. Sayles; Nickel-Zinc Corronizing, L. C. Conradi; Hot-Dip Galvanizing, H. J. Volker.—INCO.

Combatting the Corrosion of Condenser Parts of Locomotives. S. G. VEDENKIN and E. R. ANISIMOVA. Tekh. Zheleznykh Dorog. **5,** 7, 18-20 (1946); Chem. Abs., **41,** 5, 1196 (1947) Mar. 10.

A study was made of anticorrosion protection of finned copper tubes of locomotive condensers. The copper tubes are provided with 666 tin-plate fins, coated and soldered to the tube by immersion in a melt comprising lead 83%, tin 10%, and antimony 7%. In spite of the protective coating, the fins rust. The corrosion is attributed to the potential difference between the iron and the coating of the fins. A comparative study was made of the corrodibility of steel fins (uncoated), sheets of the lead-tin-antimony alloy, and of zinc-base alloys. Most advantageous was a coating of zinc-aluminum alloy containing 0.2% of aluminum. A corrosion-resistance test was made with a large number of steels for the purpose of finding a more resistant steel than the one used at present for making parts of the water-feeding assembly, Khalilov 51 and 89 steels, containing carbon 0.09% and 0.14%, copper 0.37% and 0.34%, chromium 0.41% and 0.56%, and nickel 0.39% and 0.33%, respectively, proved most resistant. A study was also made of protective coatings for the outside and inside of pipes. Bakelite varnish and paints were best.—INCO.

Review of an Investigation of Ceramic Coatings for Metallic Turbine Parts and other High-Temperature Applications. W. N. HARRISON, D. G. MOORE, J. C. RICHMOND (Nat. Bur. Stds.) NACA Tech. Note 1186, 17 pp. (1947) Mar.

Refractory frits of high thermal expansivity were applied as coating to various heat resistant alloys, such as C-590, S-816, 2520 + 2% silicon, Inconel, 18-8. Coated specimens were heated at high temperatures in air without load and tested for adherence, resistance to flaking, protective value against oxidation, resistance to deterioration, and stress-rupture. Accelerated tests were also made at high temperatures in H_2S-contaminated atmospheres. Data indicated that some ceramic coatings provide a high degree of protection for heat resistant alloys in strongly corrosive atmospheres at high temperature, preventing or greatly retarding surface oxidation in air at 1500° F. for at least 500 hours. At loads low enough

to ensure a life of over 600 hours for uncoated alloy specimens, some of the coatings added significantly to time required for failure. Alloys S-590 and S-816 retained their initial 0.2% offset yield values in high temperature treatments when coated, whereas uncoated specimens were almost completely disintegrated. Graphs, tables, specimens, and test equipment are shown.
—INCO.

Effect of Various Clays on Permeability of Ground-Coat Enamel Slips and Oxidation Behavior of Metal. R. L. COOK and B. B. SCHILLER. Univ. of Ill., Paper before Am. Ceramic Soc. 49th Annual Meeting, Chicago, Apr., 1946; Am. Ceramic Soc. Bull., **26**, 3, 67-68 (1947) Mar. 15.

The permeability of several clay slips to the passage of water was compared with that of the same clays when used in ground-coat enamels. The progressive weight changes taking place in the firing of ground-coat enamel on metal was followed analytically. The total water loss from the clay apparently would influence the amount of oxide formed. The tests also indicate a possible correlation between the permeability of the enamel slip and the total weight of oxide formed in firing.—INCO.

German Glass or Enamel Lined Equipment on Mild Steel and Cast Iron for Chemical, Food, Drink and Allied Industries. Brit. Intelligence Objectives Sub-Comm., 1945. Final Report 569, R. M. Stationery Office; Bull. Iron & Steel Inst., **129**, 77A, (1946) Sept.

An account is given of the methods used by German firms for lining steel tanks, vessels, and pans with glass and enamel so that they can be used for transporting wine, beer, and milk.—INCO.

Rolled Stainless Steels. F. L. LAQUE, International Nickel Co., Paper before ASM, Montreal Chapt., (1947) Mar. 3; Canadian Metals & Metall. Inds., **4**, 25 + (1947) Apr.

Discussion of common grades of rolled stainless steel including their applications is presented. Steels are referred to by their AISI numbers. Those discussed are: type 301, 303, 304, 308, 309, 310, 316, 317, 321, 347, 410, 414, 416, 420, 430, 440, 446, 502, and stainless W.—INCO.

CORROSION TESTING

Marine Exposure Tests on Stainless Steel Sheet. WILLARD MUTCHLER, National Advisory Committee for Aeronautics, Washington, 26 pp., (1947) Feb.

Final report on the corrosion tests of stainless steel sheets included in the marine exposure programs from 1938 to 1945.—BLR.

Acidic Atmosphere Evaluation of Cleaning on the Corrosion of Steel. C. W. SMITH, Detrex Corp., Paper before 89th Gen. Mtg., Electrochem. Soc., Birmingham, Ala., Apr. 11, 1946; Electrochem. Soc. Trans. **89**, 127-44 (1946).

The "acidic atmosphere cell" was used as a means of evaluating different cleaning materials and methods in regard to their effect upon the corrodibility of bright steel. Cleaning methods using either abrasives or alkaline compounds, or volatile, partially volatile, or emul-

sified solvents were compared as to effects on bright steel when exposed in the "acidic atmosphere cell." Emulsified solvent cleaning materials which leave a film of nonvolatile emulsifier render steel surfaces the least corrodible. Steel cleaned with such materials can usually be further processed by inspection, machining, bonderizing, or painting without any additional cleaning step and may be held over for indefinite periods without corroding in an industrial atmosphere.

Intergranular Corrosion of Chrome-Manganese Steels. L. SCHAEBEN. From Korros. & Metallschutz, **19,** 44-46 (1943) HENRY BRUTCHER, Alta-dena, Calif. (Translation No. 1486).

Describes compositions and uses of austenitic and austenitic-ferritic chromium-manganese steels and a short-time laboratory test for intergranular corrosion. Gives results for the three steels tested. Makes recommendations for avoidance of intergranular corrosion.—BLR.

Resistance of Aluminium-Base Alloys to Marine Exposures. R. B. MEARS and R. H. BROWN, Trans. Soc. Naval Architects Marine Engrs., **52,** 91-113, (1944); Chem. Abs., **40,** 6390 (1946) Nov. 10.

Various uses of aluminium in marine construction from 1894 to date are reviewed. The nature and location of tests are described. Zinc will cathodically protect aluminium alloys in sea water. Magnesium-base alloys cause special cathodic corrosion, but aluminium-base alloys containing substantial amounts of magnesium are resistant. If aluminium alloys must be used with copper or copper alloys, immersed in sea water, cathodic protection by means of zinc attachments is satisfactory; if exposed to the atmosphere, complete electric insulation of the aluminium from the copper is necessary. If this is not feasible, the copper parts should be given a heavy coating of cadmium. Sealing the joints between the aluminium and copper with a caulking composition and then painting all exposed surfaces of both the aluminium and the copper is sometimes effective when exposed to the atmosphere. Details and photographs are given of actual tests and the results are tabulated. Discussions and 11 references are included.—ALL.

Corrosion Resistance of Magnesium Alloy Sheet in Contact with Dissimilar Metals. W. R. WHITMORE, P.B., 1411, 17 pp. (1946).

The results of an investigation of the effect of ten dissimilar metal contacts on the corrosion resistance of magnesium sheet are presented. In most of the tests, the panels were of magnesium with plate attachments of the 10 dissimilar metals, but in one test, the panels were made of dissimilar alloys and magnesium plates were attached. The only other variable was the corrosion inhibiting paint used on the fraying surfaces. The spray coats employed were various combinations of zinc chromate primer and aluminized lacquer. The panels and plates were assembled with AM55S rivets and were put on tidewater racks at Chapman Field, Florida. The tests showed that the edges of the contacting surfaces were most

subject to corrosion. Contact with aluminium alloys, with the exception of 53S which was the most satisfactory of all the couples tried, resulted in severe corrosion of both aluminium and magnesium. The application of zinc chromate primer did not increase corrosion resistance. Steel was the most corrosive of all the couples used, and neither cadmium plating nor zinc chromate primer improved the corrosion resistance of the steel-magnesium couple.—ALL.

FUNDAMENTALS

Hydrogen in Steel. J. H. ANDREW, H. LES, A. K. MALLIK and A. G. QUARRELL. Iron & Steel, **19,** 665-681 (1946) Nov. 21; discussion 766-789; Metals Rev., **20,** 1, 14 (1947) Jan.

Work undertaken to determine the temperature at which hydrogen can most readily be removed, and in what way this temperature depends upon the composition of the steel. Formation of hairline cracks. All experiments carried out on normal commercial steel.—INCO.

Internal Oxidation. F. N. RHINES Corr. & Mat. Prot., **4,** 2, 15-20 (1947) Mar.-Apr.

The present status of the knowledge of internal oxidation (subscale formation) has been reviewed. This is a diffusion process wherein the more reactive component of an alloy is oxidized within the alloy by the inward diffusion of oxygen. The rate of advance of the front of oxidation is controlled co-operatively by the diffusion rates of oxygen and the reacting element. Attempts to show a hardening effect by precipitated oxides, analogous to the age hardening effect, have been fruitless. Precipitated oxides appear to influence the modes of recrystal lization and grain growth.

Graphite Formation in Cast Irons and in Nickel-Carbon and Cobalt-Carbon Alloys. H. MORROGH and W. J. WILLIAMS. (B.C.I.R.A.) J. Iron & Steel Inst., **155,** 321-372 (1947) Mar.

Literature was reviewed and investigations carried out by authors to study and develop some analogies between process of graphite formation in cast irons and in nickel-carbon and cobalt-carbon alloys, to confirm findings of Eash that undercooling in cast irons occurs with solidification of a white-iron structure which subsequently decomposes after solidification to give undercooled graphite, to extend this idea to high-silicon irons and nickel-carbon and cobalt-carbon alloys, and to examine the possibility of nodular graphite occurring in arsenic-cast cast irons. It was concluded that some analogies held and Eash's findings were confirmed. The effect of tin and zirconium in refining graphite depends on presence of carbides of these elements. Two types of inverse chill were demonstrated. A detailed description of the metallography of graphite in relation to its crystal structure is given with over 100 microstructures shown. Undercooling in nickel-carbon, nickel-iron-carbon, and cobalt-carbon alloys and in cast irons takes place by solidification of a eutectic of solid solution carbide, and the carbide phase decomposes after solidification. Coarse graphitic structures solidify as a eutectic of solid solution graphite. Nickel-carbon and cobalt-carbon al-

SIX BITUMASTICS . . . FOR STUBBORN DEFENSE AGAINST CORROSION AND RUST

- BITUMASTIC* BLACK SOLUTION
- BITUMASTIC SUPER-SERVICE BLACK
- BITUMASTIC TANK SOLUTION
- BITUMASTIC HI-HEAT GRAY
- BITUMASTIC "50"
- BITUPLASTIC*

THEY ARE TOUGH—

Bitumastic protective coatings are tough! Their base of carefully refined coal tar pitch is a natural seal against corrosion. Each of the six products listed above has its specific application in the continuing battle against rust and corrosion.

AND THICK!

The coatings are thick. Bitumastic #50 for example covers with a thickness of 1/64" to the coat—about 5 times the thickness of paint. Successive applications can provide a seamless, non-porous sheath up to 1/16" in thickness. Coatings are applied cold with either a brush or spray gun.

When you have surfaces of metal, masonry or concrete exposed to corrosive conditions, seal them against premature deterioration with one of the six Koppers Protective Coatings.

BE SURE TO SPECIFY GENUINE BITUMASTIC

Suggestions for the correct use of Bitumastics and Bituplastic are given in our folder "Corrosion."

The Bitumastic Bulletin is devoted to the selection and application of Koppers protective coatings, and is a regular publication. Send us your name and business address and we'll be glad to put you on the mailing list.

KOPPERS COMPANY, INC.

WAILES DOVE-HERMISTON DEPARTMENT
WESTFIELD, NEW JERSEY

*REG. U. S. PAT. OFF.

KOPPERS PROTECTIVE COATINGS K KOPPERS

loys tend to give coarse graphite when they contain more than a certain amount of sulfur. In absence of sulfur additions, spherulitic nodular structures may be produced in nickel-carbon, nickel-rich nickel-iron-carbon and cobalt-carbon alloys by addition of calcium and or magnesium in a variety of forms (calcium-silicon, calcium-copper, calcium-magnesium, barium-magnesium, etc.). Spherulitic nodular graphite can occur without heat treatment under conditions described. Undercooling of cast irons and similar alloys is discussed at length. Cooling curves are shown. —INCO.

Effect of the Solvent on Hydrogen Overpotential. J. O'M BROCKRIS. Nature, **158,** 584 (1946) Oct. 26; Corr. & Mat. Prot., **4,** 1, 28 (1947) Jan.-Feb.

Measurements of hydrogen overpotential have been made, mostly at high current densities on lead, copper, and nickel cathodes in a number of solutions. The solvent effect was found to be marked in some systems. The overpotential on lead is generally less in non-aqueous than in aqueous solutions, and sometimes has a tendency to pass through well defined Maxima and minima at intermediate compositions. On nickel cathodes there is usually a less marked effect of a different type, and more complex variations tend to occur. The behavior of copper cathodes resembles that of lead. —INCO.

The Resistance of Metals to Scaling. B. LUSTMAN, Westinghouse Research Labs. Paper prepared for ASM Metals Handbook, (1947); Metal Prog., **50** 5, 850-856+ (1946) Nov.

Theory and mathematical calculations involved in scaling of metals and alloys, structure, chemical composition, melting and boiling points of scale formed, methods for determining oxidation resistance effect of various alloys and impurities on oxidation ressitance, and classifications of metals and alloys forming protective, non-protective and interface oxide films or layers are discussed. Penetration of oxygen into steel is increased by nickel additions (6% nickel increasing depth of internal oxidation about 4 times) as a result of a higher solubility of oxygen in nickel-containing steels. Cobalt and molybdenum behave similarly. Presence of these oxidized zones leads to pickling difficulties and causes surface cracks during hot working. A digram shows constituents of scale layers in iron-nickel-chromium alloys at 1830° F. maximum temperatures of stability of copper, iron, brass, nickel, chromium, chromium-iron alloys, nickel-chromium-iron alloys, chromium-nickel alloys and chromium-iron-aluminium alloys are tabulated. An appendix gives dissociation pressures of oxides formed on various solid metals including nickel. 24 references.—INCO.

GAS AND CONDENSATE WELL CORROSION

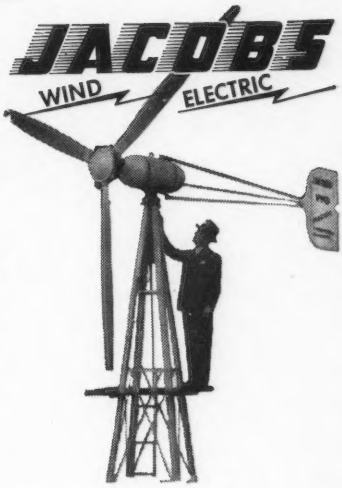
Preventing Corrosion in Gas Condensate Wells. P. L. MENAUL and P. P. SPAFFORD, Stanolind Oil & Gas Co. Paper before AIME, N. Y., Mar. 17-22, 1947. Abstr. Oil Weekly, **125,** 3, 50-1 (1947) Mar. 17.

Remedial measures against corrosion in gas condensate fields were

THE NEW JACOBS WIND ELECTRIC SYSTEM
—NOW OFFERS CONTINUOUS PIPELINE PROTECTION
Guaranteed 5 Years Unconditionally
AGAINST BURNOUT or DEFECTS

Jacobs Wind Electric Plants have been recognized for many years as the cheapest source of direct current available along the pipelines of America. Calm periods, however, have in the past allowed some corrosion to take place at a few intervals per year.

The new Jacobs system utilizes a combination method of a few strategically placed magnesium anodes and the new Jacobs Wind Electric Plant to deliver 100% pipeline cathodic protection current.



The anodes are inactive when the wind electric plant is supplying sufficient current, but automatically pick up the load during calm periods. Anode life is increased many times, and only a comparatively few are required with this system. Equipped with automatic electric relays.

The new greatly improved Jacobs Wind Electric Plant is almost attention-free. Its maintenance cost per 10-year period is far below that of any other method of supplying cathodic protection.

Write for literature and prices.

THE JACOBS WIND ELECTRIC COMPANY, INC.
Pipeline Division
MINNEAPOLIS 11, MINNESOTA

undertaken with amonium hydroxide and "bone oil" previously found effective in laboratory experiments by Stanolind Oil & Gas Co. in preventing corrosion of steel in condensate well waters. A 26% ammonium hydroxide solution was introduced in the annulus between tubing and casing by means of a gravity-type chemical feeder connected to the casing wing, and circulated up the tubing with the well production. The casing annulus must be free of packers or other obstructions. Daily injection of a small quantity of the chemical proved effective in entirely preventing this type of corrosion.

Corrosion Problems in High-Pressure Distillate Wells. R. L. Hock, Cotton Valley Operators Committee. Paper before NGAA Corrosion Res. Proj. Comm. Dallas, Texas, Oct. 17, 1946. Oil Weekly, **124,** 9, 33-5 (1947) Jan. 27.

Measures used for the detection and control of corrosion in high pressure distillate wells by the Cotton Valley Field Operators Committee are described. Corrosion control cost is $0.47327/MMcf, exclusive of insurance value, or reduced efficiencies of leaky strings or production loss through ruptured equipment. The cost figure is broken down by types. Routine control measures include systematic visual inspection for corrosion and leaks, penetron surveys, electrical surveys to determine need for insulating wells from flowlines, and use of tubing calipers. Since corrosion of high pressure gas gathering lines occurs mainly on the bottom of the inside of the line, periodic rotation of the pipe through 90° or 180° angles increases its life. Christmas trees are insulated from piping by dielectric gaskets to eliminate electrolysis. Preliminary tests appear to favor naphthenic acid in mineral seal oil solution as an inhibitor over sodium chromate and others. Gravity injection of inhibitors is being tried and promises many advantages over use of mechanical pumps. The corrosion rates of wells are approximately linear functions of their production rates, and wells in this field flowing over 5 MMcf/day develop an excessive corrosion rate. Hence too high a production rate per well is uneconomical.

Review of Corrosion Literature for 1945. Electrochem. Soc. Trans. **89,** 41-74 (1946).

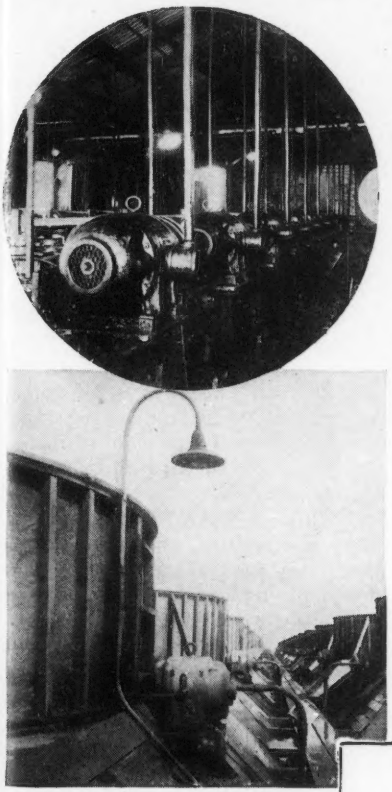
Review articles by various authors are presented on the following aspects of corrosion and corrosion prevention: theory of corrosion, cathodic protection, inhibitors, electrodeposited coatings, protective coatings, including surface conversion coatings and plastics, soil corrosion, atmospheric corrosion, cavitation, corrosion and embrittlement by boiler waters, corrosion in chemical engineering, corrosion by organisms, corrosion in sea water, corrosion in oil fields, corrosion testing apparatus and methods, electrochemical methods in corrosion, and corrosion of bearings and bearing alloys. Copious literature references are included with each article.

Remedies Studied for Freakish Corrosion Occurring in Some Condensate Fields. D. P. Thornton. Pet. Processing, **2,** 273+ (1947) Apr.

Three years' study of the cause of the spotty attacks of corrosion ex-

10 YEARS OF EXPOSURE

...and EVERDUR Conduit sets notable service record in Port Arthur refinery



"At the Port Arthur, Texas Plant of The Texas Company, Everdur Conduit is used for protecting motor circuits from corrosive vapors in the Acid Centrifuge Building. Also in lighting systems on No. 2 Alkylation Unit Cooling Tower and FCCU Cooling Tower."

INSTALLED IN 1937 in the Acid Centrifuge Building of The Texas Company's Port Arthur, Texas Plant, Everdur* Electrical Conduit shows no evidence of deterioration—despite constant exposure to corrosive vapors. Other installations of Everdur Conduit at this plant resist the attack of moist salt air in outdoor locations.

Everdur Copper-Silicon Alloys are characterized by high strength and excellent resistance to corrosion. Installations made since 1933 have shown time and again that where ordinary conduit fails in months, Everdur Conduit lasts for years. It is available in two wall thicknesses, rigid conduit (RC) in nominal sizes ¼" to 4" inclusive, and the thinner walled Electrical Metallic Tubing (EMT) in nominal sizes ⅜" to 2" inclusive. Complete lines of fittings ... connectors, couplings, outlet boxes, etc. ... are available in Everdur Alloys from leading manufacturers.

*Reg. U. S. Pat. Off.

47216-A

ANACONDA
from mine to consumer

Everdur

ELECTRICAL CONDUIT

THE AMERICAN BRASS COMPANY

General Offices: Waterbury 88, Connecticut

Subsidiary of Anaconda Copper Mining Company

In Canada: ANACONDA AMERICAN BRASS LTD.
New Toronto, Ont.

perienced in gas-condensate fields indicates that lower fatty acids found in well fluids in minute concentrations are a principal promoting agent. Various types of chemical inhibitors are being tried with varying degrees of relief. Plastics or other forms of coating are also being investigated.—BLR.

Corrosion in High Pressure Gas Condensate Wells. J. W. WAECHTER, Univ. Texas. Paper before AIME Texas Sec., Austin Dec. 18-19, 1946. Abstr. Oil Weekly **124**, 4, 32 (1946) Dec. 23.

Effectiveness of anti-corrosion agents in gas condensate wells against corrosion caused by carbonic acid, lower fatty acids such as formic, acetic and propionic acid, and hydrogen sulfide is discussed. Among the agents mentioned are: naphthenic acid dissolved in mineral oil, sodium dichromate, Kontol 115, and thermo-reacting and thermo-setting plastics. Inhibitors that form protective layers seem to be the most effective. The majority of corrosion problems and successful means of coping with them hinge on the accurate determination and classification of the causative agents.

METAL FAILURE

Corrosion Ratings for Metals. H. D. HOLLER and R. A. FRYE. Corrosion, **3**, 8-22, (1947) Jan.

Discusses the difficult problem of providing tables or equations for the prediction of corrosion resistance of metals. Presents tables for various commercial alloys and points out their limitations in the atmosphere and sea water. The alloys studied include aluminum, magnesium, iron-nickel-chromium, nickel and nickel copper and copper and its alloys.

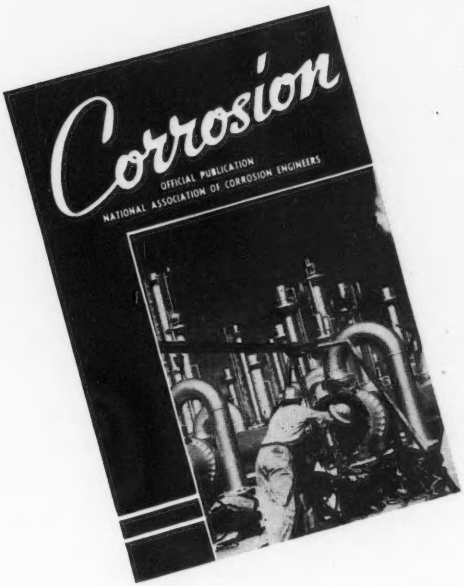
Thermogalvanic Corrosion. N. E. BERRY, Servel, Inc. Corrosion, **2**, 261-267 (1946) Nov.

Thermogalvanic corrosion is defined, its theory and the implications discussed and its possibility with various metals analyzed. A thermogalvanic copper cell is used as an example and concrete occurrences in service mentioned. Thermogalvanic corrosion is galvanic corrosion which occurs when a metal in contact with an acidified solution of its own salt which ordinarily will not corrode, corrodes when a substantial temperature differential exists between separated areas. Thermogalvanic behavior and data for a copper cell are presented. Thermogalvanic corrosion may occur in ferrous metal systems, although in neutral or alkaline solutions the possibility is limited because the concentration of ferrous or ferric ion is limited by the solubility of their hydroxides. The author suggests that even gold might be attacked under the conditions considered. Concrete examples of the phenomena mentioned are an all-steel evaporator for concentrating sodium citrate solutions, and caustic evaporators and fusion pots. Thermogalvanic and concentration cells are contracted.—INCO.

Corrosion in Crevices. E. H. WYCHE, Titanium Alloy Mfg. Co. Paper before 89th Gen. Mtg. Electrochem. Soc. Birmingham, Ala., Apr. 11, 1946; Electrochem. Soc. Trans. **89**, 149-166 (1946).

The nature of corrosion in crevices and its occurrence are described. Sea water tests on various crevice

The Authority in Its Field



Dedicated
To
Service
For All
Industry

CONCENTRATED COVERAGE....

• CORROSION reaches a majority of corrosion engineers throughout the world, being distributed in 36 foreign countries besides the United States and Canada. Here is the medium to reach this highly concentrated group of specialists—the men who specify and recommend the materials, equipments, services and devices their companies use in combating corrosion.

For rates and mechanical specifications write:

A. B. CAMPBELL, Executive Secretary,
National Association of Corrosion Engineers
905 Southern Standard Building, 711 Main Street
HOUSTON 2, TEXAS

sealing compounds are reviewed, petrolatum being found most effective. Practical suggestions for avoiding crevice corrosion are listed.

Corrosion Resistance of Magnesium and AZ80x Magnesium Alloy Castings Containing Small Proportions of Silver and Lead. R. R. ROGERS and W. DINGLEY, The Canadian Mining and Metall. Bull. (Canada), **50,** 418, 49-56 (1947) Feb.

This article is based on the assumption that magnesium alloys containing small proportions of lead or silver might be more resistant to the corrosion of chloride solutions than the same alloys without lead or silver. A number of accelerated chloride corrosion tests on AZ80x magnesium-alloy castings with and without silver or lead additions were performed. This particular alloy was chosen because it is frequently used in this country for making castings. A similar series of alloys in which silver or lead was added to commercially pure magnesium was tested for comparison. All castings were of the permanent mould type. On the basis of the results of this investigation, the following conclusions may be drawn: 1) the addition of 0.1 percent lead, or 0.05 percent lead plus 0.05 percent silver, particularly the former, can be expected to increase considerably the corrosion resistance of AZ80x magnesium-alloy castings when exposed to aqueous salt (sodium chloride) solutions under total immersion, intermittent immersion, or spray conditions; 2) the addition of 0.5 percent lead +0.5 percent silver to castings of this type may produce slight improvement in the corrosion rate under these conditions; 3) the addition of 1 percent lead or 1 percent silver or 0.1 percent silver to castings of this type can be expected to increase considerably their corrosion rate under these conditions; 4) the addition of lead and/or silver to commercially pure magnesium castings in the amounts used in this investigation can be expected to decrease their resistance to corrosion under these conditions.—ALL.

The Corrosion of Metals—VI. The Corrosion of Copper and Its Alloys. Sheet Metal Inds., **23,** 2159-2164 (1946) Nov.; Ibid, **24,** 145-151+ (1947) Jan.

An extensive review article with numerous graphs and tables on galvanic corrosion of copper and copper alloys, season cracking of brass (effect of internal stresses, and composition, prevention of attack, and season-cracking test), corrosion of copper-zinc alloys, dezincification (alloys subject to this, types of factors favoring it, effect of addition of arsenic, antimony, phosphorous and tin). 116 references.—INCO.

Nonferrous Metals — Annual Review. J. ANTHONY. Iron Age, **159,** 1, 104-109 (1947) Jan. 2.

General survey of nonferrous metals situation in 1946. Use of molybdenum as an alloy in steel has increased until it is now added to more than three quarters of the alloy steels. Developments of deposits of nickel in Cuba and Russia have cut Sudbury production to 75% from 90% total of world production. Present status of the Petsamo mines and the Cuban nickel project, a predicted large demand for nickel due to increased use of stainless steel and heat and corrosion resistant alloys,

Insuring Pipe Line Performance

Above illustrations show typical installations of pipe line coated with Reilly Enamel

THE performance and maintenance cost of a pipe line depend upon the degree of protection rendered by the coating. The best insurance of uninterrupted pipe line performance and low maintenance costs is the use of Reilly coatings.

Whether the line runs through river bottoms or swamps, under rivers or over mountains—whether the temperature is below zero or tropical—Reilly Enamel gives dependable protection against all corrosive agencies. The tough, durable Reilly coating completely seals and insulates the steel against extraneous materials and the elements, thus preventing the corrosive agencies from coming in contact with the metal. Reilly Enamel also effectively resists soil stress and abrasion, and withstands temperatures as high as 160°F. without flow or sag and as low as minus 20°F. without checking or cracking.

Booklet describing Reilly Protective Coatings for all types of surfaces will be sent on request.

REILLY TAR & CHEMICAL CORPORATION
Merchants Bank Bldg., Indianapolis 4, Indiana
500 Fifth Ave., New York 18 • 2513 S. Damen Ave., Chicago 8

Reilly Protective Coatings

as well continued use of triple alloy steels, and the price increase of nickel, are commented upon. The other chief non-ferrous metals are all discussed.—INCO.

WATER CORROSION

Experience Shows Amines Stop Corrosion. R. S. MONCRIEF AND M. E. DREYFUS. Power, **91,** 1, 19-21 (1947) Jan.

Severe corrosion problems were encountered in the feed pumps, deaerating trays and heaters of a large Louisiana steam plant due to oxygen scavenged by the corroding metal from the condensate and feed-water at their low pH range of 6.8-7.0. A water soluble amine (composition not given) was introduced into the system at an initial rate of 4 ppm. and additional amine was added at the rate of 1½ to 2½ ppm. regularly. All equipment previously subject to active corrosion was found to operate over long periods without giving any trouble. A description of the plant is included.

Tuberculation Measurement as an Index of Corrosion and Corrosion Control. EDWIN W. BARBEE. J. AWWA, **39,** 220-230 (1947) Mar.

Describes an extensive investigation made in order to measure the relative corrosiveness of San Francisco water and determine the most efficient and practical corrective treatment. Results indicate that measurement of head losses over a period of several months reflects the corrosiveness of raw or treated water, thus permitting valid comparisons among various treatments. One ppm sodium pyrophosphate or hexametaphosphate gave comparable protection.—BLR.

Abbreviations at end of abstracts indicate contributors cooperating in conjunction with the American Coordinating Committee on Corrosion, and the National Association of Corrosion Engineers to reproduce all abstracts pertaining to corrosion under one cover, in the NACE journal, Corrosion, and are as follows:

Aluminum Laboratories, Ltd. (The Abstract Bulletin)	*ALL*
American Society for Metals (Metals Review)	*MR*
American Society for Refrigerating Engineers (Refrigeration Abstracts)	*RA*
American Water Works Association (Journal)	*AWWA*
Battelle Memorial Institute Library (Battelle Library Review)	*BLR*
Calco Chemical Division, American Cyanamide Corp.	*CALCO*
Consolidated Edison Co. of New York, Inc.	*CEC*
General Petroleum Corp., of California	*GPC*
International Nickel Co., Inc.	*INCO*
Institute of Aeronautical Sciences, Inc. (Aeronautical Review)	*AER*
Institute of Metals, London, Eng. (Metallurgical Abstracts)	*MA*
Institute of Petroleum	*IP*
McGraw Hill Publishing Co. (Electrical World)	*EW*
(Chemical Engineering)	*CE*
National Bureau of Standards	*NBS*
Revue de Metallurgie	*RM*
Universal Oil Products	*UOP*